

**Water and Environmental Research Institute of the
Western Pacific
Annual Technical Report
FY 2013**

Introduction

The Water & Environmental Research Institute of the Western Pacific or WERI is one of 54 similar water research institutes set up by U.S. Congressional legislation at each Land Grant University in the United States and in several territories. The Institute is now in its 40th year of operation.

WERI's mission is to seek solutions through research, teaching and outreach programs, to issues and problems associated with the location, production, distribution, and management of freshwater resources. The Institute provides its regional stakeholders with technical expertise in a diversity of water resources related fields including tropical climatology, surface water hydrology, rainfall catchment systems, groundwater modeling and management, water distribution systems, soil erosion and mitigation strategies, watershed management, and various aspects of water quality. Faculty members contribute significantly to both undergraduate and graduate teaching programs at the University of Guam (UOG) and conduct vigorous research aimed at improving economic conditions and the quality of life for citizens of Guam and the regional island nations. WERI also operates a state of the technology water analytical laboratory and geographical information systems analysis and training facility.

WERI administers and carries out research, training, and other information transfer programs under a variety of federal and local funding sources, but the Institute was created specifically to administer Department of Interior funds (via the US Geological Survey) under Section 104-B of the Water Resources Research Act. WERI has responsibility for the administration of three 104-B base grants: one for Guam, one for the Commonwealth of the Northern Mariana Islands (CNMI), and one for the Federated States of Micronesia (FSM). This report summarizes the Institute's regional activities under the USGS 104-B base grant program for the period March 1, 2013 to February 28, 2014 (FY13).

Currently WERI has a full-time Director who is also a UOG faculty member, five (5) regular and one (1) emeritus research faculty, a water analysis laboratory manager and technician, one staff hydrologist that administrates the GIS and network system, two office staff, as well as five (5) graduate research assistants who are completing their MS degree in the UOG Environmental Sciences program.

During FY13, WERI faculties were involved as principal investigators and/or advisors on twenty three (23) research and training projects with a combined budget of approximately \$1,011,762. Funding sources for these projects, in addition to the US Geological Survey, included the National Oceanic and Atmospheric Administration, the National Weather Service, the National Science Foundation, USGS Pacific Islands Climate Science Center (PICSC), the US Military, and local agencies such as the Guam Bureau of Statistics and Plans, the Guam Environmental Protection Agency, the Guam Waterworks Authority, and direct appropriations from the Guam Legislature.

Over the same time frame, WERI faculty and staff taught eleven (11) graduate courses in the Environmental Science MS program. At the same time WERI faculty were first or second authors on ten (10) refereed journal articles, eight (8) conference proceedings papers, six (6) technical reports, and seventeen (17) professional presentations. WERI faculty members served on seventeen (17) thesis committees of students in the Environmental Science and Biology MS programs and chaired nine (9) of them.

Following is a list of non USGS funding sources and associated projects carried out by the Institute during the 2013-2014 reporting period:

DIRECT LOCAL FUNDING FROM THE GUAM LEGISLATURE SUPPORTS: A. The Guam Comprehensive Water Monitoring Program, a 50:50 cost sharing program with Hawaii District, USGS B. The Guam Hydrologic Survey, which in turn has provided funding over this fiscal year for the following projects:

1. Guam Geologic Map Update and Revision; 2. Reconstructing the Climate History of Guam; 3. Temporal and Spatial Variations in Guam's Groundwater Quality.

GUAM BUREAU OF STATISTICS AND PLANS HAS PROVIDED FUNDS TO: 1. Assessment of Turbidity in the Geus River Watershed in Southern Guam; 2. Provide GIS Technical Support for GIS Applications for Watershed Management Projects for Guam's Priority Watersheds; 3. Develop Digital Atlas of Northern Guam; 4. Provide GIS Assessment Tool for Determining Cumulative and Secondary Impacts from Increase Development on Guam; 5. GIS Technical Support for GIS Applications Master Planning and Land Use; 6. GIS Application for Wetland Delineation Mapping.

GUAM WATERWORKS AUTHORITY AND NAVFAC MARIANAS HAVE PROVIDED FUNDS TO: 1. Determine if Guam's Northern Aquifer Should be classified as Groundwater under the Direct Influence of Surface Water (GWUDI) in Accordance with the Safe Drinking Water Act, Surface Water Treatment Rule; 2. A Study on Influence of Seawater on Biological Treatment on Guam, CNMI, and FSM.

NATIONAL SCIENCE FOUNDATION HAS PROVIDED FUNDS TO: 1. Examine the Holocene Hydrologic Variability Across the Western Pacific Warm Pool.

NATIONAL WEATHER SERVICE HAS PROVIDED FUNDS TO: 1. Pacific ENSO Applications Center with University of Hawaii: JIMAR Project, Climate Forecast & Information; 2. Pacific ENSO Applications Center with University of Hawaii: JIMAR Project, Development of an Extended and Long-Range Precipitation System over the Pacific Islands; 3. Pacific ENSO Application Center-NOAA, Department of Commerce; 4. Pacific Island Climate Science Center with University of Hawaii.

Research Program Introduction

The Water and Environmental Research Institute (WERI) Advisory Council is the body, which determines research goals and priorities for WERI in general and the USGS 104-B program in particular. The Research Advisory Council (RAC) for Guam consists of representatives from all Guam governmental agencies involved with water resources development or regulation, members of U.S. Federal agencies, military organizations on Guam that deal with water resources issues and members of the university research community. The RAC for the Commonwealth of the Northern Mariana Islands (CNMI) and the Federated States of Micronesia (FSM) consist of representatives from various government departments that deal with water resources, representatives from the local colleges, private sector engineers, environmentalists, and planners, and University of Guam research faculty.

WERI held RAC meetings in September through October 2013. Twenty six (26) people attended the Guam meeting, fourteen (14) attended the FSM meeting, and nineteen (19) attended the CNMI meeting. The meetings provided a scientific forum for information exchange on new and recently completed projects. Each RAC group examined the research education and training priorities identified in past years and added or amended where appropriate.

In early November, a Request for Proposals (RFP) letter was sent out by e-mail to over two hundred (200) regional representatives in Guam, the CNMI and FSM. Recipients included all past and present RAC members; faculty members at the University of Guam, the Northern Marianas College in Saipan and the College of Micronesia in Pohnpei, and water resource professionals from several government agencies. Accompanying the RFP message were: a) a blank proposal form for submittal on the USGS Web Site, b) detailed instructions on how to fill out the form, and c) the critical water resource research, education and training needs identified for Guam, the CNMI and FSM.

Nine (9) research proposals, three (3) for Guam, four (4) for the CNMI and two (2) for the FSM; four (4) environmental educational programs, three (3) for Guam, one (1) for the FSM; and two (2) information transfer and training program, one (1) for Guam, and one (1) for FSM, were submitted for consideration in response to the RFP for FY14. Three regional review panels, each composed of well qualified water resources professionals and RAC members were tasked with evaluating each proposal's regional relevance in accordance with the long-standing criteria listed in the RFP. The appropriate proposals were e-mailed separately to each reviewer along with the critical needs list for the region and a scoring form. The reviewers were advised to work independently and given two weeks to submit their scores and comments to the WERI Director. The proposal scores were then tabulated and the projects ranked in descending order of average score. Projects approved for funding were selected based on their regional ranking and availability of funds.

Heavy Metal Status of Nearshore Fisheries Impacted by Old Military Dumpsites on the Eastern Side of Saipan, CNMI

Basic Information

Title:	Heavy Metal Status of Nearshore Fisheries Impacted by Old Military Dumpsites on the Eastern Side of Saipan, CNMI
Project Number:	2013GU245B
Start Date:	3/1/2013
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	N/A
Research Category:	Water Quality
Focus Category:	Toxic Substances, Water Quality, Surface Water
Descriptors:	pollution impact, monitoring and assessment, land-based and submerged dumpsites, heavy metals, drainage pathways, fisheries resources, Saipan, Micronesia
Principal Investigators:	Gary Denton

Publications

There are no publications.

Project Title: Heavy Metal Status of Nearshore Fisheries Impacted by Old Military Dumpsites on the Eastern Side of Saipan (CNMI)

Problems and Research Objectives:

The massive clean-up and redevelopment of Saipan at the end of WWII gave rise to unprecedented waste disposal problems that were largely solved by bulldozing unwanted materials into the ocean, burying them in caves, or dumping and burning them at relatively remote locations on land. Virtually every kind of material used in warfare was among the items disposed of in this way in addition to demolition and construction debris and other residual materials associated with the rebuilding effort. Twenty three such military dumpsites have so far been identified in Saipan under the *Formerly Used Defense Site (FUDS) Environmental Restoration Program* (Shimmin 2007). A number of other sites contaminated with war time and civilian wastes have been identified on the island under the *Brownfields Program* administered through the USEPA (Masga 2009). Inventories of materials disposed of at these old dumpsites indicate that unexploded ordnance, munitions and demolition materials are among the more visibly obvious wastes present (AMPRO 2005, ACOE 2007). What little chemical data exists identifies heavy metals among the more commonly encountered contaminants.

Local concerns over the possibility of contaminants migrating from these dumpsites into aquatic resources harvested for food prompted the development of a three-phase research program designed to flag the occurrence of such events. Phase 1 of this study examined heavy metal levels in soils and sediments in the immediate vicinity of several known dumpsites and from drainage pathways leading from them to the coast. Most of the sites examined were located on the eastern side of Saipan and all were found to be enriched with one or more elements (Denton and Starmer 2012). In several instances, levels encountered exceeded Saipan's environmental screening levels for shallow residential soils (DEQ 2005). Phase 2 adopted well established bioindicators (algae and limpets) to identify coastal areas impacted by these dumpsites and target sites for further evaluation (Denton and Starmer 2013). Phase 3 investigations focused on metal profiles in popular food fish from these targeted sites and assessed human health risks associated with their long-term consumption. The methodological details and major findings of this latter phase of the study are described herein.

Methodology:

Coastal areas identified as potentially problematic from a fisheries contamination standpoint were the submerged lands adjacent to Agingan Point, Naftan Point and Naftan Cliff area, at the southern end of the island, and Bird Island and Banzai Cliff along the northern perimeter (Fig. 1). Brief notes on each site are provided below and include analytical highlights from media examined during the earlier phases of the program.

Site Descriptions:

1. Agingan Point: a rocky peninsula at the southern end of Saipan Lagoon that served as a tipping point for the ocean disposal of civilian wastes for several years up until the mid-1970s. Visible reminders of this past practice remain on the seabed beneath the point and in the lagoon to this day. Submerged sediments collected just east of the point during Phase 1 of the study were found to be heavily contaminated with lead (1500-2000 µg/g) and substantially enriched with copper (100-160 µg/g) and mercury (60-140 ng/g). While Phase 2

bioindicators from this site mirrored the ambient lead enrichment, levels of all other elements analyzed in them were within normal ranges.

2. Naftan Point: a densely vegetated ravine at the southern end of the point that was used for surplus ordnance disposal and the burning of military wastes after WWII. Impacted soils in the area were found to be heavily contaminated with lead (1600-2000 µg/g), copper (1400-12000 µg/g) and mercury (400-600 ng/g). In the marked absence of conspicuous drainage pathways from the ravine to the coast, stormwater seepage through the surrounding limestone topography was assumed to be the primary mode of contaminant transport to the ocean. Bioindicators from the ocean-side entrance to the ravine revealed normal ranges of all metals examined. Submerged sediments were not collected during the site inspection because of prohibitive sea and surf conditions.
3. Naftan Cliff: a plateau atop a steep, limestone escarpment that was used for the disposal of surplus ordnance and munitions at the end of WWII. Ordnance fragments were widely scattered along the cliff-line, presumably impacting the ocean below during the detonation process. Surface soils were obviously contaminated with lead (70-75 µg/g), copper (160-180 µg/g) and mercury (60-90 ng/g), although not to the same extent as found on the point further south. Contaminant transport to the ocean from this flat, exposed site is largely facilitated by windblown dust and water infiltration through the limestone overlay. Inclement weather conditions prevented submerged sediment and bioindicator collections at this site.
4. Bird Island: targeted for further evaluation only after abnormal cadmium levels (1.6-1.7 µg/g) were discovered in beach deposits down gradient of a small ephemeral stream that discharged into the adjacent bay area. Interestingly, cadmium enrichment at this site was also evident in resident bioindicators analyzed during Phase 2 of the study.
5. Banzai Cliff: originally used as a tipping platform for the dumping of military garbage directly into the ocean at the end of WWII, it was later adopted for the disposal of unexploded ordnance by the same principle. The latter practice continued on and off up until the mid-1960s, eventually covering the adjacent seabed with a huge array of artillery shells, bombs and other munitions. According to one report, an attempt to detonate the ordnance in place resulted in a large section of cliff-face fracturing and falling into the ocean (AMPRO 2005). Submerged sediments collected close to the tipping point were found to be substantially contaminated with copper (500-1500 µg/g) and lead (70-100 µg/g). Surprisingly, however, only light mercury enrichment (14-16 ng/g) was evident. Hazardous seas at this site prevented the collection of bioindicators during Phase 2 operations.

Fish Sampling:

Three common food-fish types were selected for this work. They included the two herbivores, *Acanthurus lineatus* (surgeonfish) and *Naso lituratus* (unicornfish), and the planktivore, *Myripristis* spp. (soldierfish). Both *A. lineatus* and *Myripristis* have restricted foraging ranges. Contaminant profiles in these individuals were thus considered to be representative of their collection sites. All specimens were captured either by hook and line or spear-gun. They were transported to the laboratory on ice and deep-frozen for transportation to Guam. Axial muscle samples of thawed specimens were removed from immediately below the dorsal fin of each fish using seawater-resistant, stainless steel instruments. Excised tissues were placed in clean polypropylene vials, weighed and stored at -20°C until required for metal analysis.

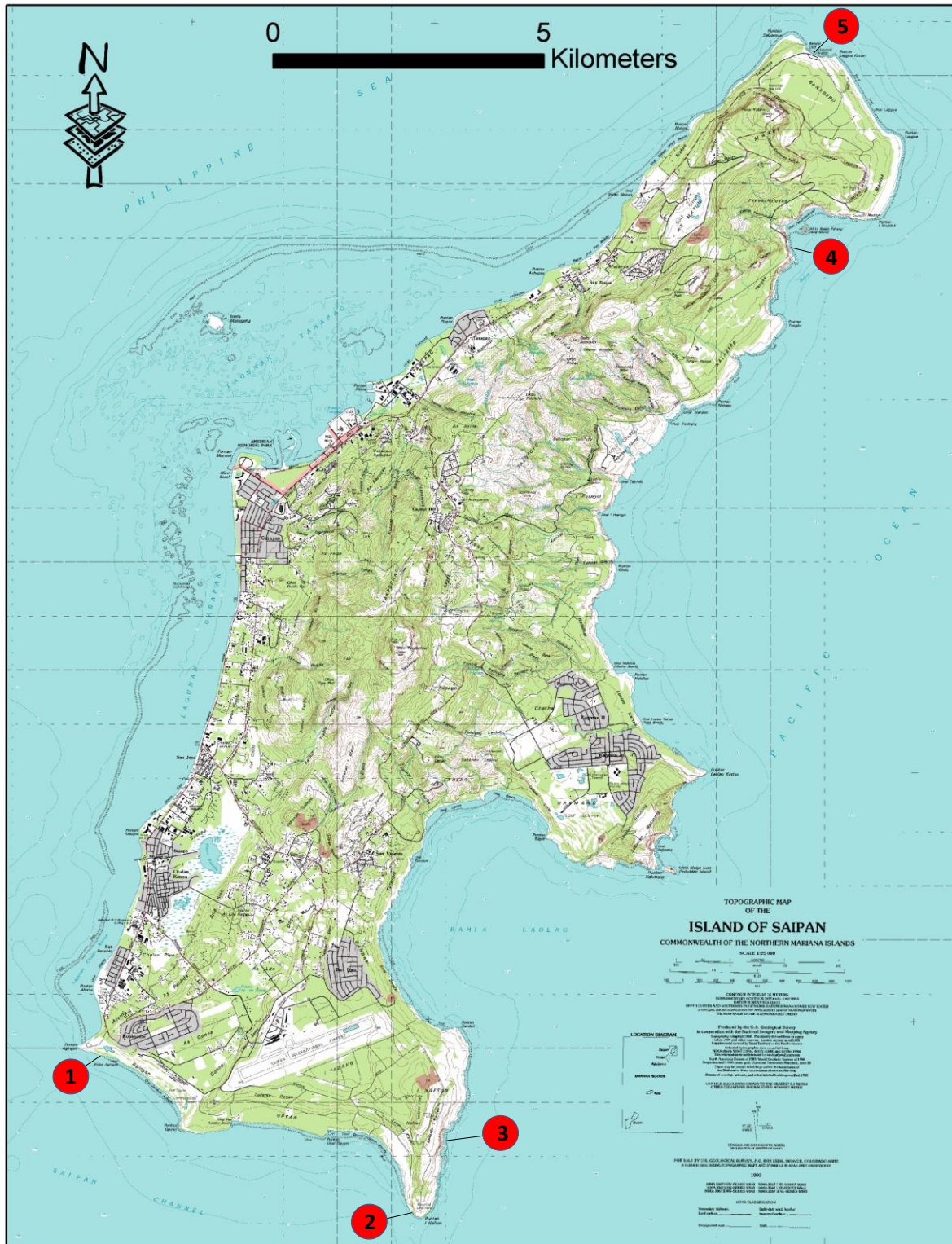


Figure 1: USGS 1-25000 topographic map of Saipan (15°12'N, 145°43'E) showing Phase 3 study sites in the vicinity of Agingan Point (sites 1), Naftan Point (site 2), Naftan Cliff (site 3), Bird Island Bay (site 4), and Banzai Cliff (site 5).

Sample Analysis:

Samples analyzed for mercury were wet digested in 2:1 nitric/sulfuric acids at 100°C for 3 hours, made up to volume with distilled water and analyzed by flameless Atomic Absorption Spectroscopy (AAS) using the syringe technique developed by Stainton (1971). Samples for all other metal were dried to constant weight at 60°C, digested in nitric acid at 125°C until oxidation was complete, and then analyzed by conventional AAS. Corrections for non-atomic absorption were made simultaneously by the instrument. Quality control and quality assurance procedures were rigidly adhered to. Recoveries for all elements from standard reference materials were in good agreement with certified values.

Principle Findings and Significance:

The analytical findings are summarized for each fish type in Table 1. No adjustments were made for percentage recoveries from tissue spikes and standard reference materials. Heavy metal concentrations typically found in the axial muscle of tropical marine fish from relatively clean coastal waters are shown in Table 2. It can be seen that the great majority of values recorded during the present study fell within these normal ranges.

Fish are able to regulate essential metal levels in their tissues to within narrow limits dictated largely by their physiological needs (Phillips 1980, Watanabe *et al.* 1997). As such, they are not particularly sensitive indicators of common metal contaminants like zinc and copper. They also possess relatively low affinities for non-essential metals of toxicological significance like silver, cadmium and lead. Mercury, on the other hand, is readily accumulated by fish and can reach prohibitively high levels from a human consumption standpoint in long-lived, predatory species (Denton and Breck 1981). Mercury concentrations determined in the current work were clearly trophic level-dependent exemplifying the well known capacity of this element to bioaccumulate.

Public health risks associated with eating mercury contaminated fish are exacerbated by the fact that this element is predominantly present in the highly toxic, methylated form (Storelli *et al.* 2005). USEPA fish consumption guidelines for the general population recommend that fish with methylmercury concentrations in their muscle tissue above 0.088 µg/g wet weight should not be eaten on an unrestricted basis. The equivalent benchmark value for sensitive subgroups is 0.029 µg/g wet weight (USEPA 2000). Mercury levels in all herbivorous fish captured in this study were well below these values. In *Myripristis*, however, exceedences of the lower benchmark were noted in certain representatives from all sites, while occasional exceedences of the upper value were seen in fish from the Naftan Point and the Banzai Cliff areas.

The mercury data for *Myripristis* from all sites are graphically presented in Fig. 2 and generally show size-dependent relationships. Linear regression analysis of the pooled data-sets revealed distinct data-point clustering above and below the line for the Banzai Cliff and Bird Island representatives respectively. It also clearly separated out Naftan Point fish as the most contaminated after their body weights were taken into account. Inter-site discrepancies in fish size ranges were accounted for by normalizing these data to a standard 16 cm fish length (~median size) using the linear regression equations generated for each site. Normalized mercury values in descending order of concentration were as follows: 0.080 µg/g for Naftan Point (site 2), 0.055 µg/g for Banzai Cliff (site 5), 0.042 µg/g for Naftan Cliff (site 3), 0.036 µg/g for Agingan Point (site 1) and 0.032 µg/g for Bird Island (site 4).

Table 1: Heavy Metal Concentrations in Axial Muscle of Fish Representatives from Targeted Coastal Waters Sites in Saipan

Fish	Site	N	Statistic ^a	Ag	Cd	Cr	Cu	Fe	Hg ^b	Mn	Ni	Pb	Zn
<i>Acanthurus lineatus</i> ^c													
1. Agingan Point	7	Mean:	nc	nc	nc	0.56	7.15	0.001	0.26	nc	nc	12.3	
		Range:	all <0.16	all <0.16	all <0.40	0.41-0.67	4.61-12.0	0.001-0.002	0.20-0.32	all <0.45	all <0.53	10.2-13.2	
2. Naftan Point	7	Mean:	nc	nc	nc	0.36	6.42	0.002	0.31	nc	nc	10.4	
		Range:	all <0.13	all <0.13	all <0.33	0.11-0.15	3.54-8.81	0.001-0.003	0.27-0.37	all <0.31	all <0.45	9.15-11.7	
3. Naftan Cliff	4	Mean:	nc	nc	nc	0.58	8.95	0.002	0.22	nc	nc	12.1	
		Range:	all <0.15	all <0.15	all <0.32	0.31-1.29	5.02-15.3	0.002-0.002	0.22-0.28	all <0.41	all <0.51	10.0-14.6	
5. Banzai Cliff	7	Mean:	nc	nc	nc	0.37	7.12	0.002	0.23	nc	nc	11.7	
		Range:	all <0.12	all <0.12	all <0.29	0.24-0.56	3.36-31.3	0.001-0.003	0.15-0.48	all <0.32	all <0.40	8.85-15.3	
<i>Myripristis</i> spp. ^d													
1. Agingan Point	2	Mean:	nc	nc	nc	0.83	5.40	0.042	0.16	nc	nc	9.67	
		Range:	all <0.10	all <0.10	all <0.27	0.68-1.00	4.34-6.71	0.042-0.043	0.14-0.19	all <0.29	all <0.35	9.6-9.7	
2. Naftan Point	5	Mean:	nc	nc	nc	0.55	11.22	0.061	0.29	nc	nc	11.45	
		Range:	all <0.16	all <0.16	all <0.56	0.38-0.77	6.74-14.3	0.028-0.123	0.18-0.52	all <0.48	all <0.54	10.3-12.5	
3. Naftan Cliff	4	Mean:	nc	nc	nc	0.48	7.91	0.034	0.30	nc	nc	11.1	
		Range:	all <0.19	all <0.19	all <0.39	0.34-0.63	6.90-1.3	0.019-0.093	0.25-0.41	all <0.37	all <0.62	10.5-12.1	
4. Bird Island	20	Mean:	nc	nc	nc	1.23	8.78	0.02	0.25	nc	nc	11.6	
		Range:	all<0.08	all<0.08	all<0.22	0.77-2.11	5.43-15.2	0.009-0.051	0.19-0.34	all<0.13	all<0.32	9.58-13.4	
5. Banzai Cliff	12	Mean:	nc	nc	nc	0.53	7.37	0.047	0.17	nc	nc	10.6	
		Range:	all <0.15	all <0.15	all <0.35	0.39-0.89	4.89-10.8	0.019-0.166	0.08-0.30	all <0.27	all <0.51	9.6-12.0	
<i>Naso lituratus</i> ^e													
1. Agingan Point	1 ^f	Mean:	nc	nc	nc	1.30	6.68	0.003	0.27	nc	nc	26.1	
		Range:	all <0.27	all <0.27	all <0.57	1.03-1.69	4.00-8.73	0.003-0.003	0.21-0.34	all <0.68	all <0.91	23.2-30.1	
3. Naftan Cliff	5	Mean:	nc	nc	nc	0.61	7.26	0.002	0.20	nc	nc	15.6	
		Range:	all <0.11	all <0.11	all <0.22	0.44-1.15	5.53-12.3	0.002-0.002	0.14-0.26	all <0.19	all <0.35	12.3-21.7	
5. Banzai Cliff	1 ^f	Mean:	nc	nc	nc	0.72	7.52	0.002	0.27	nc	nc	18.04	
		Range:	all <0.14	all <0.14	all <0.29	0.56-0.82	6.32-8.57	0.002-0.003	0.27-0.28	all <0.34	all <0.46	15.5-20.4	

^aMeans are geometric means . Axial muscle samples from each fish were analysed in duplicate for Hg and in triplicate for all other metals^bValues for Hg are expressed on a wet wight basis. Values for all other metals were calculated on a dry weight basis. ^cHerbivore - limited foraging range.^dPlanktivore/carnivore - limited foraging range. ^eHerbivore - wide foraging range. ^fValues listed were derived from the replicate sample analyses in this instance.

Table 2: Heavy Metal Essentiality and Ranges Normally Encountered in Fish from Clean Tropical Reef Waters in Guam and the Australian Great Barrier Reef

Metal	Essential to Fish ^a	Normal range ^b (µg/g dry wt.)	This Study (µg/g dry wt.)
Ag	No	<0.1	BDL
Cd	No	<0.1	BDL
Cr	Yes	<0.2	BDL
Cu	Yes	0.1-1.0	0.11-2.11
Fe	Yes	10-50	3.36-31.3
Hg	No	<0.001-0.100 ^c	0.001-0.166
Mn	Yes	0.10-1.0	0.08-0.52
Ni	Possibly	<0.2	BDL
Pb	No	<0.5	BDL
Zn	Yes	10-20	8.85-30.1

^aAfter Watanabe *et al.* 1997; ^bCompilation of data from Burdon Jones *et al.* 1975; Denton and Burdon Jones 1986, and Denton *et al.* 1999, 2006; ^cSize/age and trophic level dependent; BDL = below detection limit (see Table 1).

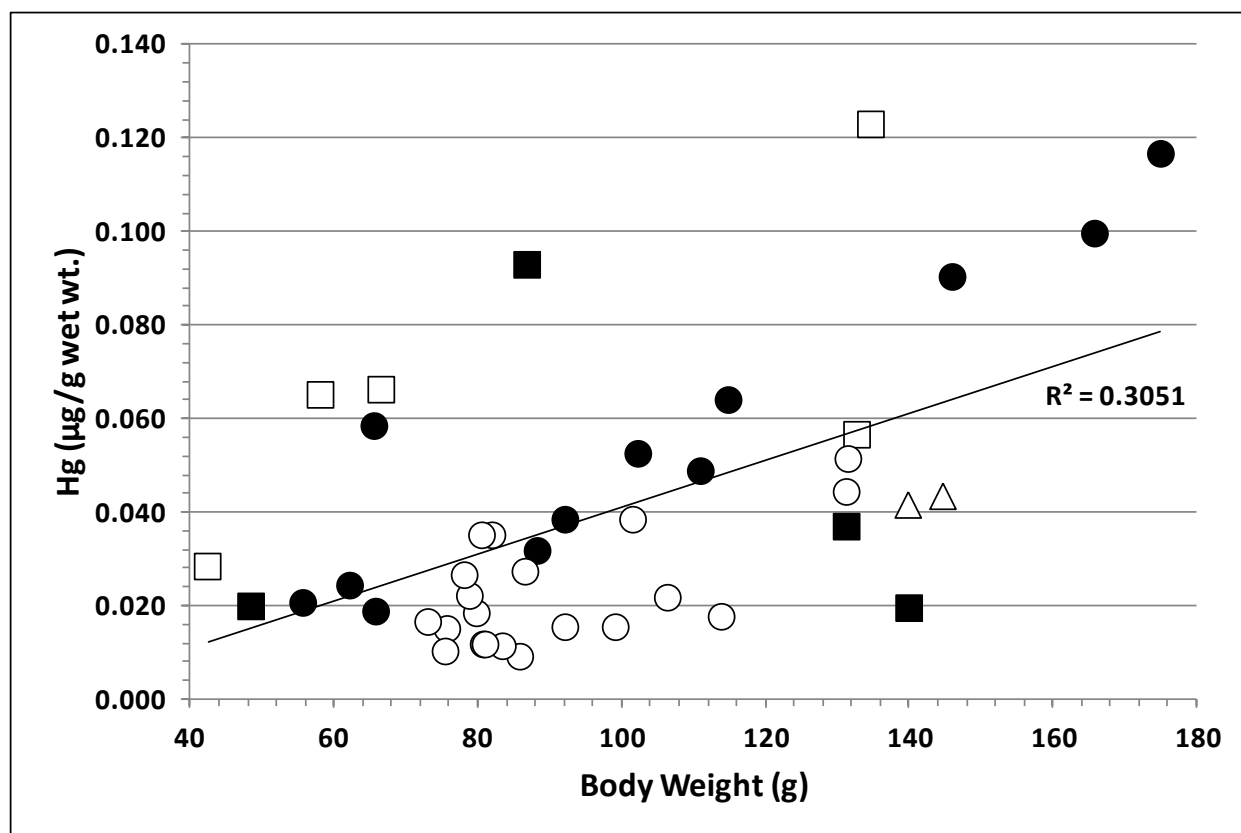


Figure 2: Scatterplots of *Myripristis* Hg data. Open triangle (Δ) = Agingan Point (site 1); Open square (□) = Naftan Point (site 2); Filled square (■) = Naftan Cliff (site 3); Open circle (○) = Bird Island (site 4); Filled circle (●) = Banzai Cliff (site 5)

Normalizing the data in this way is a convenient way of evaluating inter-site difference in mercury availability to fish, but was hampered during the present work by relatively small sample sizes – especially from Agingan Point. Nevertheless, the technique allowed for a provisional first-order assessment of all other sites examined. It also permitted a useful means of comparing data derived earlier from larger populations of *Myripristis* from clean and mercury contaminated sites on the western side of the island (Denton *et al.* 2010, 2011a & b). Normalized values for equivalent sized fish from these waters were 0.030 µg/g and 0.172 µg/g (wet weight) respectively. By inference, then, one can conclude that mercury concentrations in *Myripristis* from the Bird Island area are reasonably representative of natural baseline conditions, whereas levels encountered in fish from the Naftan Point and Bazai Cliff areas are indicative of light to moderate mercury enrichment. It would therefore be prudent to limit the consumption of larger specimens of *Myripristis* (>16 cm) and other predatory species from these two sites until additional fish analyses has been completed.

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Development of Optimum Water System Operation for Saipan Water Distribution System

Basic Information

Title:	Development of Optimum Water System Operation for Saipan Water Distribution System
Project Number:	2013GU247B
Start Date:	3/1/2013
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	N/A
Research Category:	Engineering
Focus Category:	Models, Water Supply, Management and Planning
Descriptors:	Water use data, Water demands, Distribution system, Model studies
Principal Investigators:	Mariano Iglecias, Shahram Khosrowpanah

Publications

There are no publications.

PROJECT SYNOPSIS REPORT

Project Title: Development of optimum water system operation for Saipan's Water Distribution System

The Saipan Commonwealth Utilities Corporation (CUC) has done a tremendous work to overhaul the entire water distribution system to accomplish the goal of 24-hour water service. Many additional new tanks and pipes have been added to the system, and system operation has been improved. In spite of all the new development, CUC is still not able to provide a 24-hour water service to its customers. According to US EPA water resources assessment, problems are due to inadequate inflows, system leakage, and lack of knowledge of the system's behavior as a whole.

Researchers at (WERI) developed computerized models of each of the fifteen sub-regions of the CUC water system using the Haestad WaterCAD water system modeling program. Later on, they developed a source, transmission and storage model of the Saipan water system. This includes a skeleton of the existing 15-region water system models that are joined together at the boundary points. Using Geographic Information System (GIS) capability and Saipan's 2003 census data the WERI researchers determined the number of users at each system junction node for residential and commercial customers (Heitz, Khosrowpanah 2008) as shown in Figures 1 and 2.

The next step was to better refine estimates of both the quantities and spatial distribution of water demands and how this demand changes with both residential and commercial customers during a period of time. With this information the CUC will be able to improve the operation of the water delivery system, to reduce the maintenance cost, to reduce the amount of the water that is being lost through the system, and ultimately, to improve the system operation for providing 24-hour water to its customers. The objectives of this project were to; 1) determine the average use rate for residential and commercial customers in Saipan, 2) Develop Diurnal demand pattern (changes of water demand during the day and month) for residential and commercial customers and, 3) export the data developed in step 1 and 2 into the Saipan Water System hydraulic Model, and run the model in extended period simulation mode.

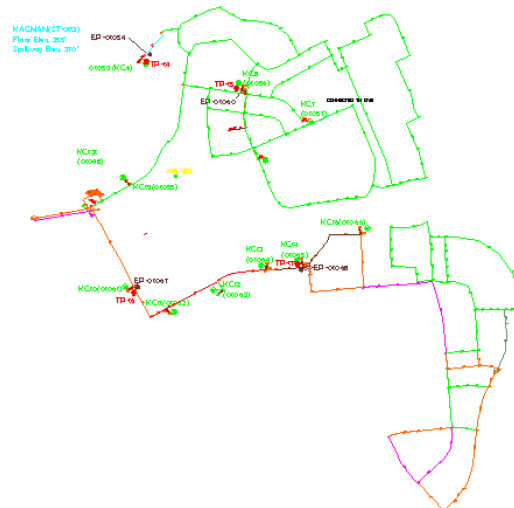
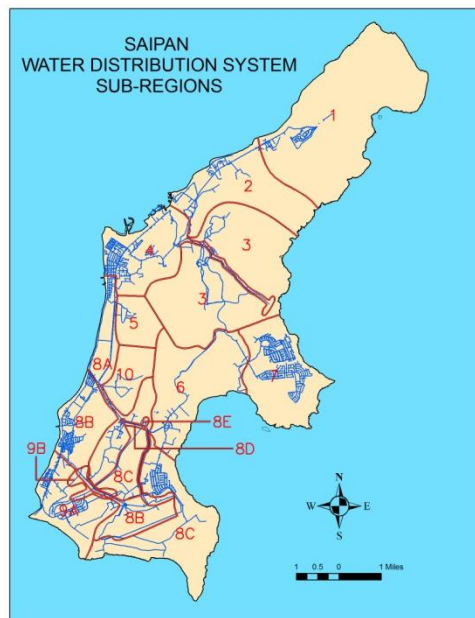


Figure 1. Saipan water distribution system and skeleton model of sub-region 7

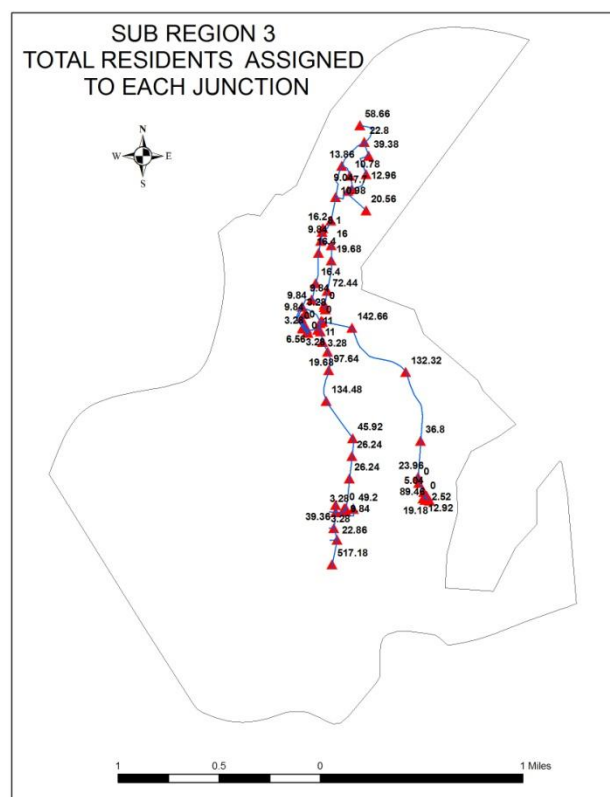


Figure 2. Sub-Region 3 Junctions Labeled With Number of People Assigned to Each Junction

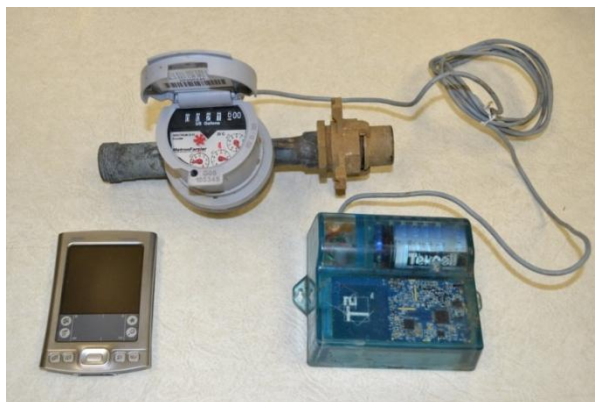
Methodology

The steps that were taken to complete the goals of this project were to: collect hourly, daily, and monthly data from the Metron Farnier meters that were installed by WERI, develop water

demand patterns for residential and selected business areas, provide this information to CUC's hydraulic model, and run the model in extended period simulation mode for system operation.

The Metron Farnier meter consists of the meter that tracks of water usage and the data logger that tracks date and time (one hour increments) and stores the water usage. The reader is Palm® PDA (Personal Digital Assistant) that communicates with the logger and extracts the data. We installed five Metron Farnier meters in Kagman – region 7 residential area that has 24-hour water service as shown in Figure 3. Meters were installed in December 20, 2012 and data collection was continued until February 2014. The Meters have been set by the manufacture to send a pulse signal to the logger for every 100 gallons water use. For data analysis we made an assumption that the water use during the 100 gallons water use stays the same within that period of time. We used 431 days of the one minute water use data to develop the average hourly water use for a period of 24 hours for residential.

Using the Metron Farnier meters for commercial water use, we encountered several problems, such as under size of the meters, and difficulty obtaining permission for installing meters. We used the monthly water use for selected customers that was reported by CUC. The next step was to import the water usage to the Saipan water system hydraulic model.



Metron Farnier Meter



Meters Location

Figure 3. Location of Installed Metron Farnier Meters

Meters Installed

No.	Meter Serial Number	Meter Number	Meter Mfg.	Meter Size	Reading Type	Meter Type	Unit of Measure	Date Installed	Begin Reading
1	G05-105091	5528	Farnier	5/8" - 3/4"	Normal	Water	Gallons	12/20/2012	142900
2	G05-089909	5384	Farnier	5/8" - 3/4"	Normal	Water	Gallons	12/20/2012	182200
3	G05-105756	2811	Farnier	5/8" - 3/4"	Normal	Water	Gallons	12/20/2012	3700
4	G05-094406	3359	Farnier	5/8" - 3/4"	Normal	Water	Gallons	12/20/2012	159400
5	G05-055230	9805	Farnier	5/8" - 3/4"	Normal	Water	Gallons	12/20/2012	58200

Meters Coordinate

No.	Customer	Household Size	North	East
1	L. Pangelinan	5	15° 10' 47.384	145° 46' 32.411
2	A. Celis	5	15° 10' 49.122	145° 46' 35.969
3	T. Towai	8	15° 10' 36.083	145° 46' 33.187
4	E. Muna	4	15° 10' 34.806	145° 46' 30.095
5	C. Salas	2	15° 10' 37.030	145° 46' 30.713

Table 1. Meter's Installed

Principal Findings and Significance

Residential Water Use: Daily average for all the five loggers and daily water usage for each person from months of December 2012 to February 2014 are shown in Figure 4. The monthly household water use increases from February to May which is during the dry season and decreases during the rainy season. According to this figure, the average daily water use for each person is 64 gallons a day.

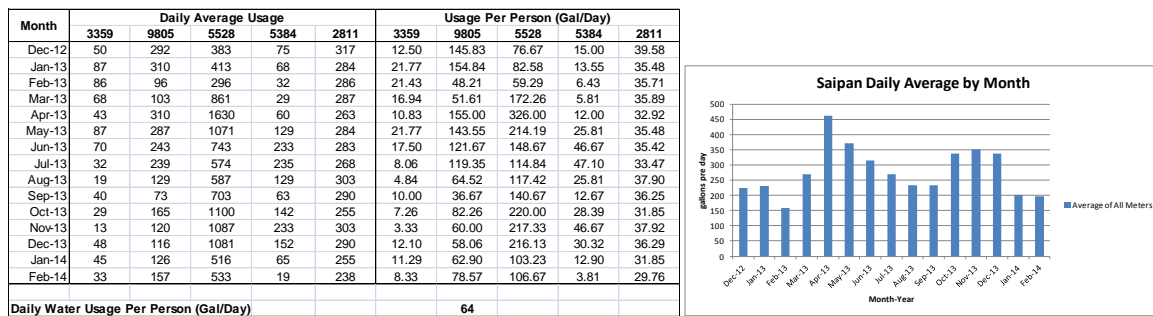


Figure 4. Daily average and daily Per/person water use (gal/day)

Diurnal Patterns for Saipan's residential water use shown in Table 2 and Figure 5. The pattern demand changes during the day. From 1 am to 6 am and 1 pm to 5 pm the percent of average hourly water use stays the same (22%) and it increases to 30 percent from 6 pm to midnight. and from 9am it increases until 8pm. The pattern (Table 2) provides a multiplying factor in order to get the correct flow value for a particular time interval.

Time (Hour)	Hourly Water Use from each Loggers (Gal.)					Average Hourly Water Use (Gal.)	Multipliers	Period Time	Period Fraction
	3359	9805	5384	5528	2811				
1	1.83	7.99	2.92	30.39	8.96	10.42	0.037	1 am to 6 am	0.22
2	1.53	7.62	2.91	30.28	8.67	10.20	0.036	7 am to 12 noon	0.26
3	1.58	7.57	2.91	30.93	7.98	10.19	0.036	1 pm to 5 pm	0.22
4	1.58	7.51	2.91	32.97	7.89	10.57	0.037	6 pm to 12 am	0.30
5	1.53	7.47	2.91	32.36	8.04	10.46	0.037		
6	1.54	8.31	3.34	33.18	8.05	10.89	0.039		
7	1.51	8.85	3.00	33.15	7.86	10.87	0.038		
8	1.50	8.77	3.83	35.47	8.14	11.54	0.041		
9	1.51	7.53	5.43	38.62	9.42	12.50	0.044		
10	1.68	7.76	5.74	37.80	9.96	12.59	0.045		
11	2.59	6.91	5.25	37.59	11.05	12.68	0.045		
12	2.67	6.91	5.56	36.32	13.20	12.93	0.046		
13	1.76	7.32	5.45	34.76	13.87	12.63	0.045		
14	1.51	6.99	5.99	33.43	13.56	12.30	0.043		
15	2.19	6.97	6.00	31.66	13.93	12.15	0.043		
16	3.58	6.54	5.95	32.65	13.90	12.52	0.044		
17	2.93	7.01	7.14	31.84	14.49	12.68	0.045		
18	1.54	6.63	7.02	31.50	15.49	12.44	0.044		
19	1.46	6.91	9.27	32.80	16.29	13.35	0.047		
20	2.20	7.84	6.71	31.30	17.06	13.02	0.046		
21	3.39	6.91	4.25	31.03	15.25	12.17	0.043		
22	3.43	7.14	3.57	30.12	13.72	11.60	0.041		
23	2.79	7.92	2.89	30.85	11.52	11.19	0.040		
24	2.30	8.58	3.32	29.93	9.88	10.80	0.038		
Sum (Gal.)						282.69			

Table 2. Hourly residential water use

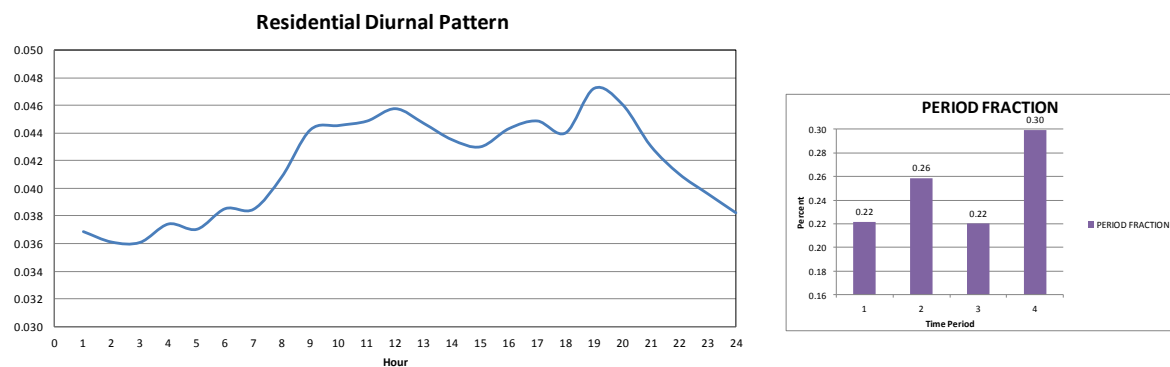


Figure 5. Residential Diurnal Pattern

Commercial water Usage: The monthly and daily water usage for selected commercial customers are shown in Table 3 and Figure 6. The hotels and Laundromats water use doesn't change significantly during the month. However, the schools water use changes during January and may-June.

Commercial Customers	January	February	March	April	May	June	Total Days	Used/Day
Laundromat	18,000		131,543	137,297	124,159	113,196	153	3,426
Seoul Washland		5,902	167,443	112,600	123,666	75,567	151	3,213
Hwa Sun Laundry	50,000	74,985	26,880	114,601	111,698		153	2,472
Total	68,000	80,887	325,866	364,498	359,523	188,763	457	9,111
Daily Average	2,194	2,889	10,512	12,150	11,598	6,292		
Kagman Elem. School	181,600	129,400	89,800	161,600	204,000	227,200	182	5,459
San Antonio School	21,043	14,839	15,553	23,024	23,864		151	651
WSR Elem. School	161,395	156,623	158,024	165,131	202,890	245,516	182	18,128
Total	364,038	300,862	263,377	349,755	430,754	472,716	515	24,238
Daily Average	11,743	6,124	8,496	11,659	13,895	15,757		
Ocean View Hotel	52,000	82,588	16,709	25,314	29,184	27,218	182	1,280
MMC-CK Beach Club	89,948	64,438	94,667	108,945	99,027	102,525	182	3,074
Century Hotel	140,504	177,656	189,926	124,281	75,110	75,680	182	4,303
Total	282,452	324,682	301,302	258,540	203,321	205,423	546	8,657
Daily Average	9,111	8,646	9,719	8,618	6,559	6,847		
Total	714,490	706,431	890,545	972,793	993,598	866,902		
Total Daily Average	7,683	5,886	9,576	10,809	10,684	9,632		
Monthly Average (per business)	89,311	88,304	98,949	108,088	110,400	123,843		

Table 3. Commercial water use

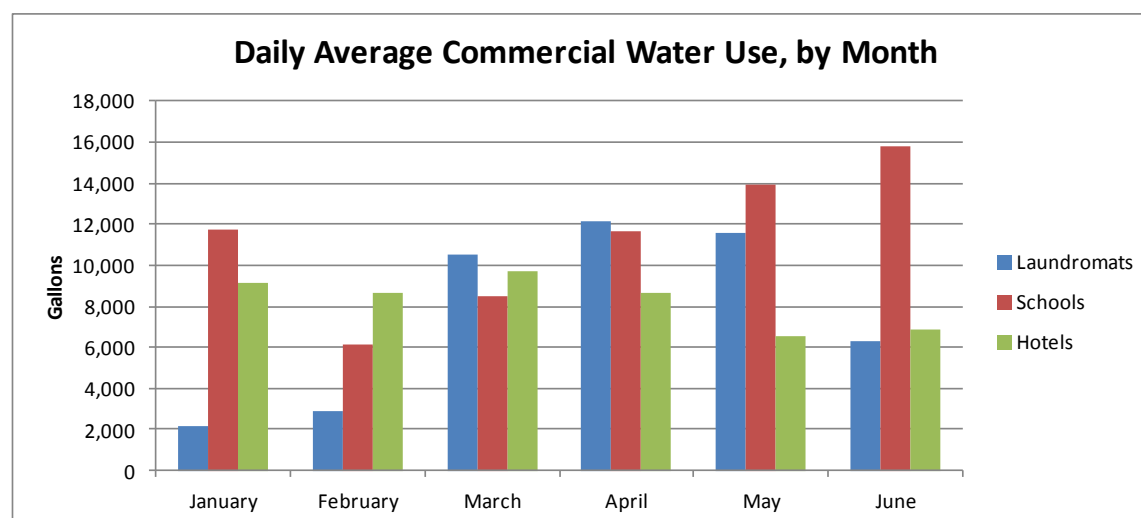


Figure 6. Daily average commercial water use

According to the CUC, average water production is 10,012,320 gallons a day. Considering Saipan's population (48,320, 2010 Census data), by using 64 gallon/person a day, the total daily water usage is 3,092,480 gallons. The CUC non-revenue water will be around 70 percent. This high unaccounted is mostly due to leakage, broken pipes, and non meter customers such as some of the farmers. We strongly recommend that CUC should emphasis on its leak detection program and a survey of the system pressure for identifying the leaks through the system.

In our previous study (Heitz, Khosrowpanah 2008) we used the 2005 census data (Population 65,000) for assigning the number of persons to each junction node. We are in the process updating the model using the 2010 population and 64 gallons/day for each user.

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- U.S. Census Bureau., "CNMI Census Data" Available at http://www2.census.gov/census_2000/. and 2010.

Land Cover Change Detection in Saipan

Basic Information

Title:	Land Cover Change Detection in Saipan
Project Number:	2013GU248B
Start Date:	3/1/2013
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	N/A
Research Category:	Social Sciences
Focus Category:	Methods, Management and Planning, Conservation
Descriptors:	Land cover change, GIS, remote sensing, Saipan
Principal Investigators:	Yuming Wen, Derek Chambers, Jose Quan

Publications

There are no publications.

PROJECT SYNOPSIS REPORT

Project Title: Land Cover Change Detection in Saipan

Problem and Research Objectives

Land cover change (LCC) has been a subject of concern for the past few decades. Land cover change is not only affected by human-induced activities, but also biophysical drivers such as droughts, flooding, earthquakes, climate change and sea level rise. Traditionally, many of the changes have been recorded qualitatively through the use of comparative photographs and historical reports. With advancement and development of geospatial technologies, it is possible to monitor land cover change and determine impacts of human activities on environment and ecosystem in islands, particularly tropical islands where water quantity and quality is essential to sustainable development and quality of life. Satellite remote sensing, spatial statistics, geographic information systems (GIS), and global positioning system (GPS) can be used to identify land cover information and determine land cover changes if temporal data are employed. Considering the global warming, sea level rise and human induced activities, many island nations or regions are facing serious problems with environmental sustainability, water resources and water quality. In order to mitigate the impacts of biophysical and human factors on environment, it is important to obtain land cover information, and determine land cover change, and evaluate whether human induced activities affect environment and water quality.

The land cover changes and the Impact of historical and recent land use activities on ground and surface water quality and production were identified as one of the highest research needs for Saipan on the CNMI Research Advisory Meeting of October 16, 2012. This project focused on derivation of land cover information from satellite images and or aerial photos, and land cover change detection in Saipan, CNMI. Available data for this project include Landsat MSS image of 1978, Landsat ETM+ imagery, and Aster L1B imagery. This project utilized moderate spatial resolution data for land cover classification and land cover change detection. Higher spatial resolution data including QuickBird, GeoEye, IKONOS data, and historical aerial photos could be employed as reference data. Geospatial technologies such as GIS, spatial analysis and remote sensing were applied to complete the project. The main objectives of this project are listed as follows:

1. Apply moderate satellite imagery such as Landsat and ASTER data to derive land cover information to determine land cover change from late 1978 to 2009,
2. Process the images such as georeferencing, removal of clouds and shadows, processing of displaced parts from Landsat imagery, and mosaicking of images,
3. Classify land cover information using satellite images and/or aerial photographs,
4. Determine land cover changes, and
5. Provide land cover and land cover change detection data and maps.

Methodology

The principal investigators (PIs) collected and processed available data such as Landsat Multi-Spectral Scanner (MSS) imagery of 1978 and Aster L1B imagery of 2009 available from EarthExplorer of United States Geological Survey (USGS, 2014). The leading PI visited Saipan

in May and October, 2013, obtained some data such as boundary of Saipan and watershed boundaries (CNMI-BECQ, 2013), discussed the main objectives of the project with collaborators from CNMI - Bureau of Environmental and Coastal Quality (BECQ), and collected Global Positioning System (GPS) coordinates and pictures for some significant features in Saipan. The geotagged pictures could be used as references to verify land cover information derived from satellite imagery (Figure 1). The GIS, remote sensing, and spatial analysis were the main technologies to obtain land cover information, and assess classification accuracy, and detect land cover changes. The GIS Lab at the Water and Environmental Research Institute (WERI) is equipped with the state of the art computers, ERDAS IMAGINE and ArcGIS software with extensions such as Spatial Analyst. ArcGIS and ERDAS Imagine were utilized to process satellite images, and both of the software were applied to conduct land cover classification. When land cover information was derived from satellite images of 1978 and 2009, land cover change could be determined, and change patterns could be evaluated.

Principal Findings and Significance

The land cover information of 1978 and 2009 for Saipan was derived from the Landsat MSS imagery of October 17 and December 10 of 1978 and the ASTER L1B imagery of March 5 of 2009. The Landsat MSS satellite imagery of October 17 and December 10 of 1978 had problems with data quality since they were covered by a lot of clouds and shadows. Some parts of the Landsat imagery of December 10, 1978 were displaced from their correct locations. ArcGIS was used to locate the displaced parts, extract the displaced parts from the original imagery of December 10, 1978, and then georeference the displaced parts to correct locations. The georeferenced parts were applied to update the original imagery of December 10, 1978. In order to improve the quality of the Landsat MSS imagery of 1978 and therefore increase the accuracy of land cover classification of the Landsat MSS imagery of 1978, both of the images of October 17 and December 10 of 1978 were used to remove some clouds and shadows. The processed and mosaicked images of 1978 were employed to derive land cover information. The data quality of ASTER L1B imagery of 2009 was very good, though two scenes of ASTER images were needed to be mosaicked to cover the island of Saipan. The land cover information was derived from the ASTER imagery of 2009. Satellite imagery of 1978 and 2009 and land cover maps of 1978 and 2009 in Saipan are listed in Figures 2 and 3 respectively. By comparison of the land cover data between 1978 and 2009, the following conclusions are made (Table 1.). Saipan was mainly covered by forest and grassland both in 1978 and 2009. The area of forest increased by 48% from 1978 to 2009, and the area of grassland decreased by about 54% between 1978 and 2009. The built-up/urban area increased by 62.5% from 1978 to 2009, and most of the increased urban areas occurred in forest and grassland. Forest change from 1978 to 2009 is shown in Figure 4.

Information about land cover and land cover change in Saipan can be applied to determine land cover change in watersheds in Saipan. There are 11 watersheds in Saipan (Figure 5), and land cover maps of 1978 and 2009 in Kagman Watershed in the Southeastern Saipan are listed in Figure 6. The land cover change information indicated that many development activities occurred from 1978 to 2009 in Kagman Watershed (Table 2). The urban area increased by about 2 times from 1978 to 2009, forest area increased by about 23%, and grassland decreased by about 54%. The land cover information can also be used to evaluate environmental concerns such as soil erosion and water quality, and it can also be utilized to evaluate whether there is

relationship between landscape change and climate change, and how land cover change affects watersheds, water quality and ecosystems in Saipan.

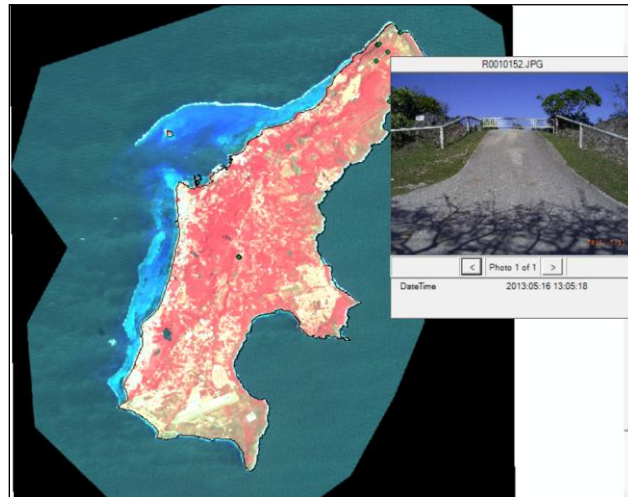


Figure 1. Geotagged picture showing features in the study area.

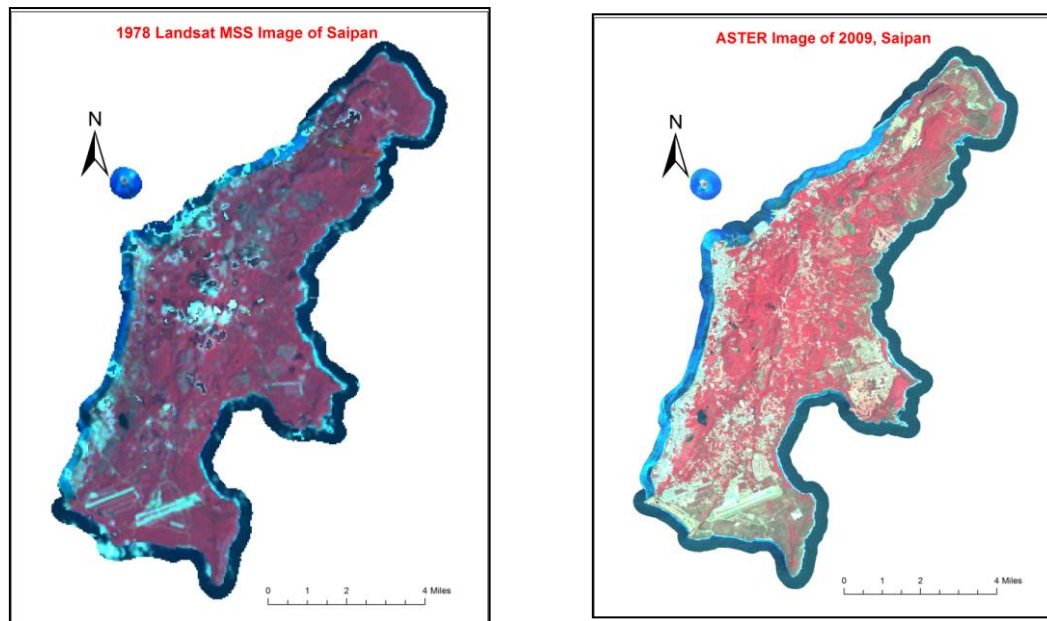


Figure 2. Satellite imagery for land cover classification. Left: Processed and mosaicked Landsat MSS imagery of 1978; Right: Mosaicked imagery of ASTER imagery of 2009.

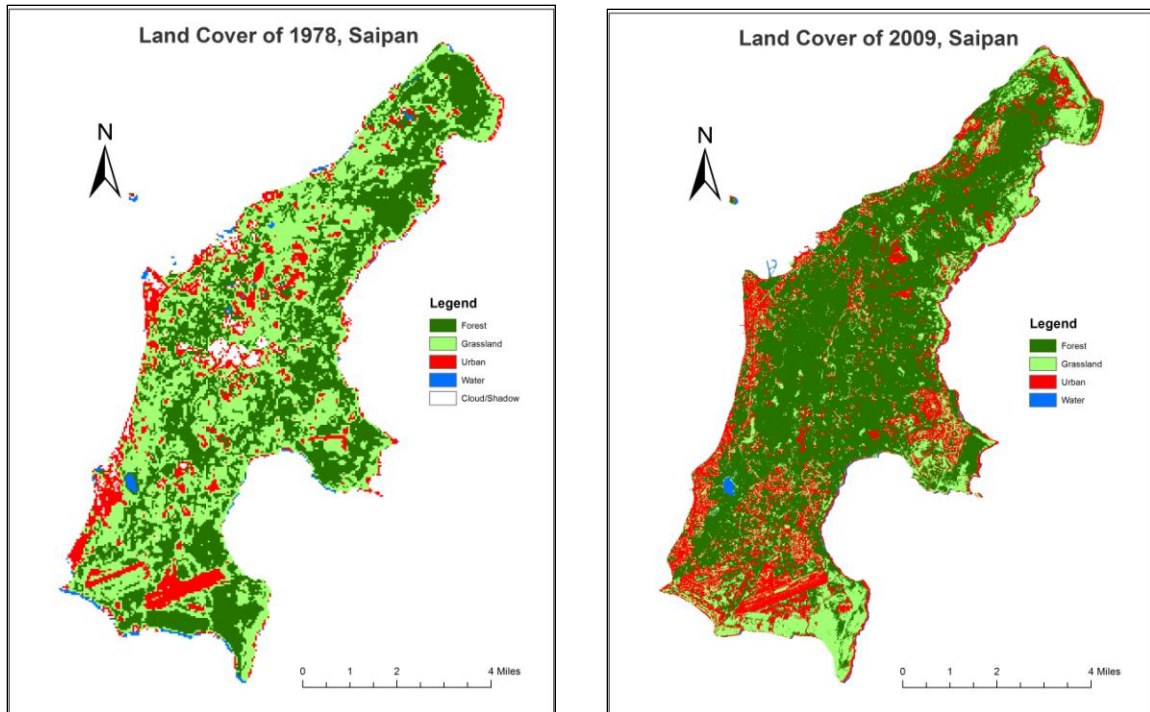


Figure 3. Land cover information of 1978 and 2009, Saipan, CNMI

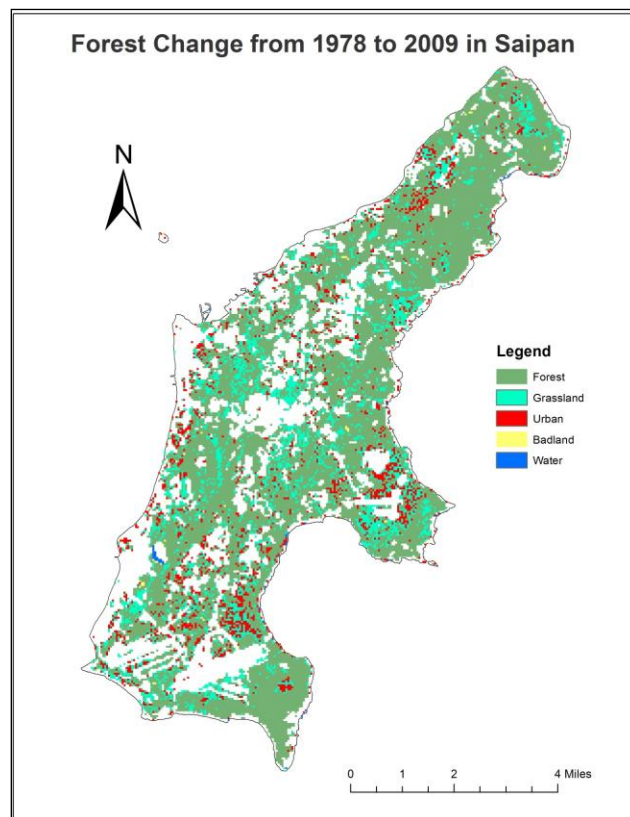


Figure 4. Forest change from 1978 to 2009 in Saipan

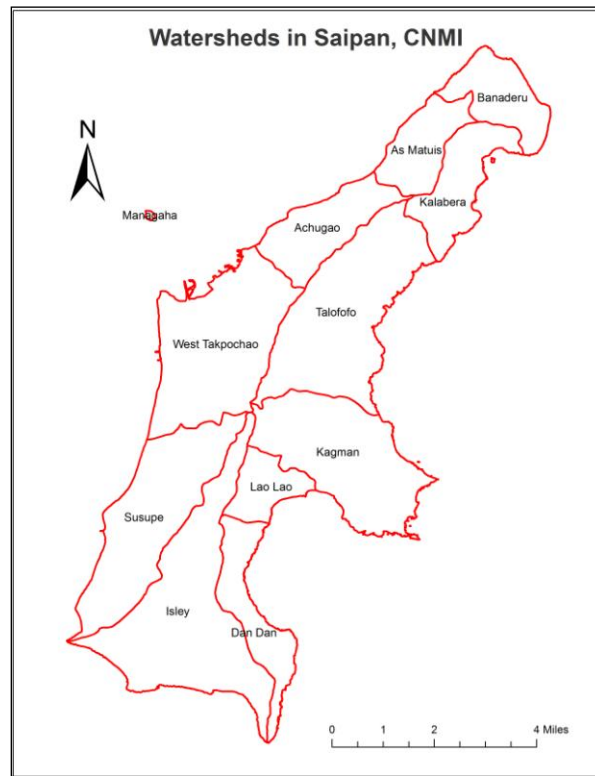


Figure 5. Watersheds in Saipan

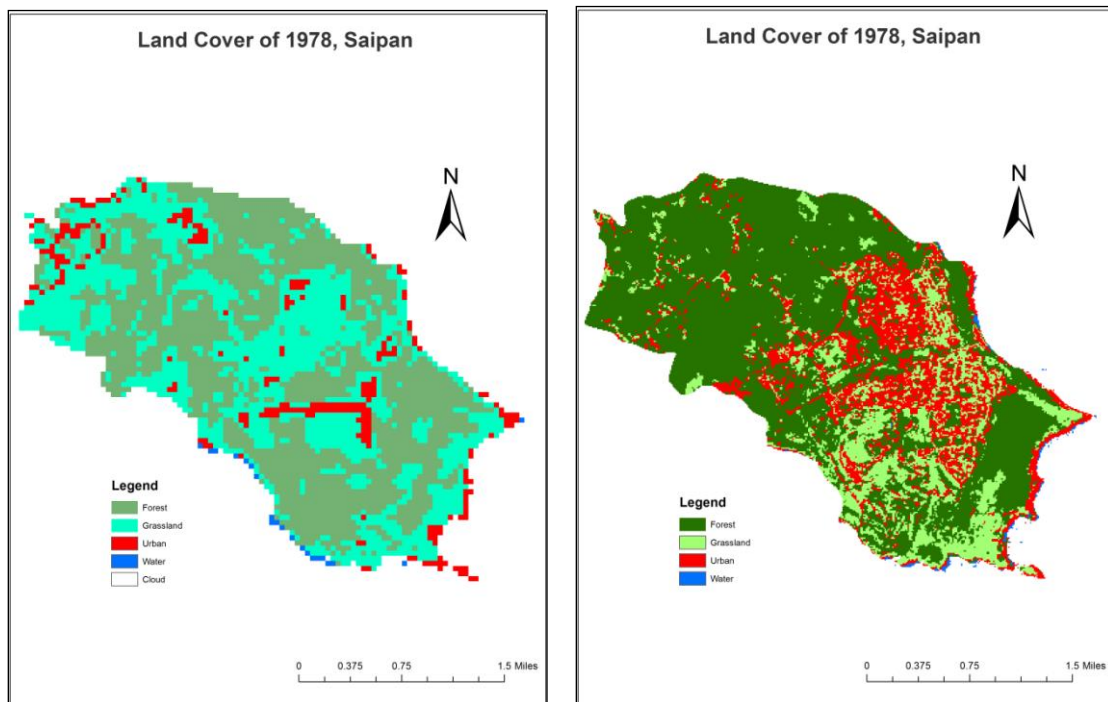


Figure 6. Land cover information of 1978 and 2009 in Kagman Watershed, Saipan

Table 1. Land cover information of 1978 and 2009 in Saipan (Unit: m²)

	LC of 1978	LC of 2009	Change rate
Forest	48283200	71468550	48.0%
Grassland	51300000	23614875	-54.0%
Urban	14338800	23301225	62.5%
Water	1328400	721575	-45.7%

Table 2. Land cover information of 1978 and 2009 in Kagman Watershed

	LC of 1978	LC of 2009	Change rate
Forest	7592400	9137025	20.3%
Grassland	6156000	2838600	-53.9%
Urban	975600	2808225	187.8%
Water	75600	60525	-19.9%

References:

1. USGS, 2014, Imagery of Landsat MSS of 1978 and ASTER L1B of 2009 downloadable from <http://earthexplorer.com> as of May 19, 2014.
2. CNMI-DEQ, 2013, Boundary of Saipan, obtained from the Division of Environmental Quality (DEQ), Bureau of Environmental and Coastal Quality (BECQ), the Commonwealth of the Northern Mariana Islands (CNMI).

Improving the Pohnpei Water Distribution System Using Hydraulic Modeling and Geographic Information Systems

Basic Information

Title:	Improving the Pohnpei Water Distribution System Using Hydraulic Modeling and Geographic Information Systems
Project Number:	2013GU249B
Start Date:	3/1/2013
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	N/A
Research Category:	Engineering
Focus Category:	Models, Water Supply, Management and Planning
Descriptors:	Water Distribution System, Geographic Information System, Water System Modeling
Principal Investigators:	Leroy F. Heitz, Shahram Khosrowpanah

Publication

1. Heitz, L.F., Shahram Khosrowpanah, 2014, Improving the Pohnpei Island Water Distribution System Using Hydraulic Modeling and Geographic Information Systems, WERI Technical Report 148, University of Guam, Mangilao, Guam, 30 pages.

PROJECT SYNOPSIS REPORT

Project Title: Improving the Pohnpei Water Distribution System Using Hydraulic Modeling and Geographic Information Systems

Problem and Research Objectives

Water hours and low delivery pressure have long been a part of the daily lives of the people in the Micronesian Islands. The problems with delivery of adequate supplies of water to the customers at appropriate pressure have become more and more of a challenge to public utilities throughout these islands. Part of these problems is due to the growth rate occurring in the island centers. This is particularly true on the island of Pohnpei in Pohnpei State, Federated States of Micronesia (FSM).

Over the years the Pohnpei Utilities Corporation (PUC) water distribution system has grown without adequate documentation as to the extent and size of supply and transmission resources and where these resources are located. In 1987 investigators from WERI developed a preliminary map and non-graphical model of the water delivery system. Since then many changes and additions have made to the delivery system.

The objective of this project was to develop a set of management and engineering tools, which the planning, operation, and engineering staffs at PUC can use to better plan, operate, and maintain the water delivery system. These tools will assist PUC develop a water system that can deliver adequate water to all the households in Pohnpei on a continuous basis with sufficient pressure.

The first management tool that was developed was a computerized water system network model. This model was developed using information gathered from previous studies and additional information documenting changes and additions to the system since the original data was gathered. Other information such as system pressure and flows was gathered as part of the calibration process of this model. The model will be available to the PUC engineering and planning staffs to help in pinpointing problems areas and to explore operations options for improving system performance. The model was developed using the free water distribution modeling program "EPANET".

The second tool developed was a Geographic Information System based (GIS) inventory of system resources. This GIS system describes the water sources available, the well systems in place, water storage facilities and major transmission lines in the distribution system. The GIS system consists of maps showing the location of the various components of the water transmission system and ancillary equipment. The GIS will be available to managers and engineers so that they can explore various scenarios for long range planning for system maintenance and improvements. The GIS will also be available to operations personnel so that they can maximize their resources for responding to emergencies, planning repairs, and purchasing the inventory of spare parts needed by the utility.

Methodology

This project was divided into three phases. These three phases are described in the following sections.

Phase I. Gather a complete physical and hydraulic description of the Pohnpei water distribution system

Information gathered during the 1987 study (Khosrowpanah, 1987) was used as the starting point for this phase. Since the EPANET model used in this study is a graphics based model, it was necessary to secure a high quality base map to use as the basis for mapping the locations of the pipes, pumps, and tanks that were part of the system. Digital Data Services, located in Lakewood, Colorado, USA, was retained to purchase a clean fresh US Geological Survey Quadrangle Topographic Map of Pohnpei Island. After procuring the map they made a high resolution digital scan of the map. This digitized map served as the base map for all of the future work that was done on the project. Along with digitizing the base map, they also created separations of the contour lines that were included on the map. These separations were later used to develop a digital elevation model (DEM) of Pohnpei. WERI researchers spent a week on Pohnpei Island working with PUC staff in order to be sure that the system maps were accurately drawn and the system component were properly characterized. PUC staff provided information on the locations and consumption rate of the high use customers in the system and updating all the system description information to present day conditions. The water model was split into water delivery zones. These zones were determined by the WERI investigators and the PUC based on previously used delivery zones and the latest meter reader routes. The delivery zones in Figure 1, were used to develop the residential demands that served as usage input to the model.

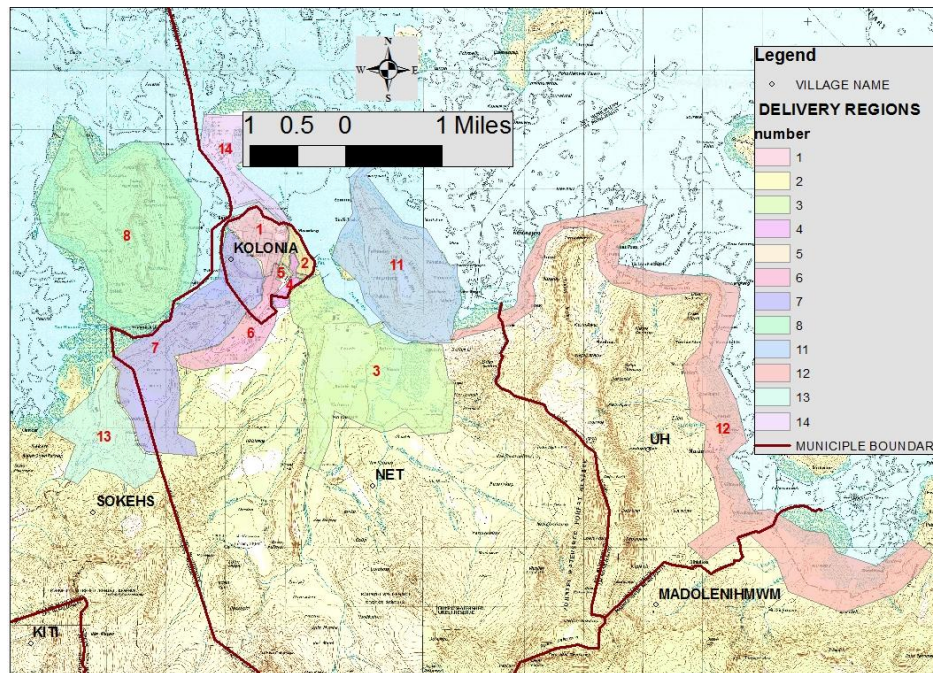


Figure 1. Water delivery zones, village boundaries, Pohnpei water

Phase II. Develop a Hydraulic Network Model of the PUC Water Transmission System

Phase II involved the development of a hydraulic network model of the PUC system using the hydraulic modeling program EPANET. This public domain (and at no cost) program was developed by the US Environmental Protection Agency (EPA) and is available on the EPA web site <http://www.epa.gov/nrmrl/wswrd/dw/epanet.html>. The model is relatively easy to use and yet very sophisticated. It can be used to model systems from the very simple to the very complex looped piping systems. It has the capability to do time simulations and therefore can model a system over days, months, or even years. By using what is called patterns the model is able to change customers' demands in order to simulate real time changing use rates in a real world environment. The model can also simulate changing water quality parameters throughout a water system, although we did not implement these capabilities in the Pohnpei model. This capability could be easily added in the future since the basic hydraulic model will already be in place. Although there are more sophisticated and more costly water system modeling programs, this program will be able to provide PUC with all the computational capabilities required for them to analyze and hopefully improve the operation of their system. Another plus for the program is the capability of other modeling programs to read the input files created by EPANET. Therefore, in the future if PUC should decide to move up to a more sophisticated model, the time and expense invested in developing the EPANET model will not be lost. A complete operational manual for the model (Rossman, 2002) is available on the USEPA Web site <http://www.epa.gov/nrmrl/wswrd/dw/epanet.html>

The data gathered in Phase I of the study was then input to the model. Figure 2. shows the entire water system network map for the Pohnpei water delivery system.

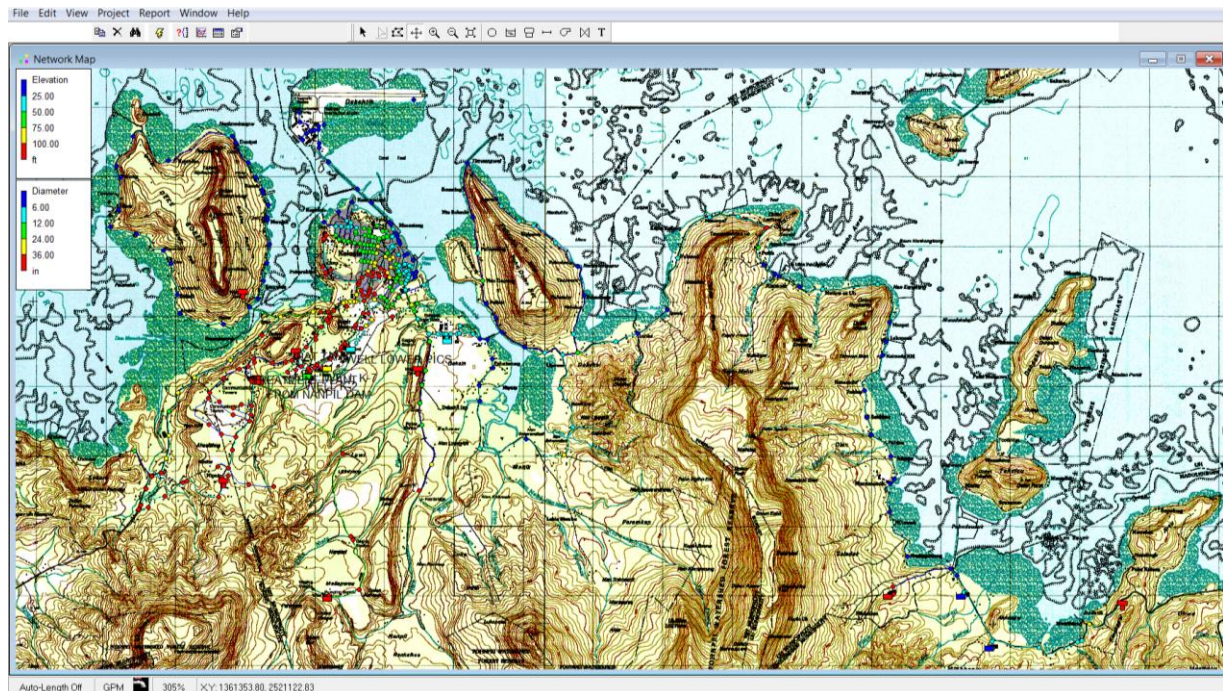


Figure 2. Entire EPANET water system network map for the Pohnpei water delivery system

Input Data for EPANET model

The next major effort came in assigning demands to the junction nodes where users require the delivery of water. A spreadsheet was developed to do all the water use rate calculations. We began first with the higher use rate customers. PUC provided data on the location and monthly consumption by the high use customers. The consumption rates were taken from monthly billing records. Table 1, shows the actual use values that were assigned to each of the high users. A junction was provided in the water system model at the location provided by PUC for each of the high users.

Problems arose when trying to apply the PUC provided customer billing data to the distribution plan outlined in the previous paragraph. It turned out that for some of the routes, there was a negative result when the high users were subtracted from the total deliveries to the route. This indicated that there was either an error in the high user amount or the totals for the routes. The PUC acknowledged that there must be an error, but were unable to provide corrected copies of the data.

An alternative strategy was adopted in order to make the model operational. The non-high-user nodes were assigned a system wide average. This average was calculated by subtracting the total for all high users from the total for all the billing routes. This remaining total was assigned equally to all of the 299 non-high user junction nodes in the model. This resulted in an average value of 2.47 gpm for each non-high-user junction.

Table 1. Actual use rates assigned to high rate users in the Pohnpei system

HIGH USER	BILLING ROUTE	ZONE	METERED AMOUNT GAL/MONTH FROM PUC	GPM FOR JUNCTION
Pohnpei State Hospital	22	3	383,570	8.76
				0.00
				0.00
Seker Elementary School	50	13	49,789	1.14
Sokehs Pah Elementary School	59	8	74,125	1.69
Sokehs Powe Elementary School	59	8		0.00
COM Kolonia 1	36	6	98,750	2.25
COM Kolonia 2		6		0.00
Ohmine School	6	1	62,070	1.42
Kolonia Elementary	24	3	278,595	6.36
Nett School	22	3	58,000	1.32
Awark School	40	12	49,871	1.14
ESDM School		12		0.00
Saladak Elementary School		12		0.00
Sports Center	31	6	3,089,730	70.54
				0.00
Hotels				0.00
South Park Hotel (Region1)	8	7	431,700	9.86
Cliff Rainbow Hotel	8	7	400,485	9.14
Joy Hotel	4	1	57,833	1.32
Yvannes Hotel		2		0.00
China Star Hotel	15	14	72,860	1.66
Sea Breeze Hotel		2		0.00
PCR Hotel	23	3	160,680	3.67
Ocean View Hotel	30	7	68,471	1.56
Pacific Sky Lite	30	7	79,140	1.81
Private Schools				0.00
PICS School	31	6	1,043,970	23.83
PICS farm	31	6	219,390	5.01
Pohnpei Catholic Schoool	2	1	29,546	0.67
Baptist School	6	1	81,012	1.85
SDA School	30	6	37,975	0.87

Table 1. (Continued) Actual use rates assigned to high rate users in the Pohnpei system

HIGH USER	BILLING ROUTE	ZONE	METERED AMOUNT GAL/MONTH FROM PUC	GPM FOR JUNCTION
Laundromats & Commercial Stores				0.00
YTY Laundramat	36	3	88,187	2.01
Nett Laundry		3		0.00
Maupuysi laundramat	12	7	89,147	2.04
Robys Lanundry (Etchiet)	20	3	234,000	5.34
Judy Laundramat	36	6	143,160	3.27
yashidas Enterprises		2		0.00
Adams Construction	20	3	138,144	3.15
Genesis	22	3	220,245	5.03
EDA Dock Meter	15	14	642,500	14.67
Palm Terrace	26	7	66,850	1.53
Wall Mart	12	1	64,251	1.47
Isamu Nkaonw (1 and 2)	5	1	113,390	2.59
Caroline Fisheries 1	15	14	217,995	4.98
FSM Petroleum	15	14	230,505	5.26
Hawleys Ice Plant		2		0.00
True Value		2		0.00
Ace construction Company	20	3	103,485	2.36
Luen Thai	15	14	48,590	1.11
Penda Ocean	15	14	3,643,800	83.19
H & K Main Meter	19	1	166,275	3.80
Rumors Bar	26	7	111,705	2.55
Flamingo Club	26	7	50,090	1.14
Best Buy (Same as True Value)	26	7	10,780	0.25
Ambros Bakery	5	1	46,790	1.07
Caroline Fisheries 2	15	14	197,160	4.50
Linda Carl	33	7	208,365	4.76
Heigenberger Bellarmin	18	2	121,500	2.77
Pohnpei Port Authority (PPA)	15	14	151,020	3.45
Neime Preston	15	2	219,975	5.02
Pacific Food	19	2	134,940	3.08
Pohnpei Water Company	26	7	119,310	2.72
Other Government Buildings				0.00
Airport		14		0.00
Airport Fire	15	14	0	0.00
ARF	15	14	59,494	1.36
Power Plant NPP	31	7	98,255	2.24
Tuna Commision Headquarters	18	2	227,700	5.20
Telecom AGR	18	2	15,180	0.35
US Embassy	22	3	19,360	0.44
FSM Surveillance	15	14	79,275	1.81
State Legislature building		5		0.00
GRAND TOTAL ALL HIGH DEMAND USAGE			14,908,985	340.39

The portion of the PUC pumping system that was modeled consists of 6 well pumps and two lift stations as shown in Table 2. Some of the description information was obtained by field visits by WERI investigators, but the majority of the information was supplied directly by PUC.

PUMP LOCATION	MODEL WELL NAME	PUMP MODEL *	PUMP SIZE HP
WELL K-2	well_k-2	60S75-13	7.5
WELL K-7	well_k-7	135S150-9	15
WELL LOWER PICS	well_lower_pics	60S75-13	7.5
WELL NAM WELLIN ROHI	well_nam_wellin_rohi	75S30-5	3
WELL NAM KOPOTOMEN	well_namkopotomen	75S30-5	3
WELL ENRINALS	well_enrinals	75S30-5	3
TREATMENT PLANT	TREATMENT PLANT	LANE 30 HP SERIAL NUMBER 6G5-01269	30
HOSPITAL MO-PLANT	MO PLANT 1 AND 2	GRUNDFOS TYPE CR32-3-3 A-G-A-EKUBE MODEL A96419551P113070621	10
* ALL WELL PUMPS ARE GRUNDFOS			

Table 2. Wells and lift station pumps in the Pohnpei Water System

There are five tanks located in the Pohnpei system. These are shown in Table 3. It should be noted that there is a large discrepancy between the elevations shown on the PUC system diagrams and the elevations at the tank locations shown on the USGS quad maps. This could be explained by locational differences of the tanks on the quad map or local variations in elevations due to construction at the tank locations. The PUC was notified of these elevation discrepancies and were to check on the actual base elevations of the tanks.

TANK NAME	BASE ELEVATION FT FROM PUC	OVERFLOW ELEVATION FT FROM PUC	SIZE FROM PUC MG	ELEVATION FT FROM DEM
NAMPOHNMAL	370		0.5	398.3
IPAT	177	217	1.0	188.97
SOKEHS	170	210	1.0	179.59
NETT	170	210	1.0	184.42
KINAKAPW	170		0.5	259.28

Table 3. Water storage tanks in the Pohnpei water system

The tank elevations should be verified with actual surveyed elevations and the correct elevations should be applied to the tank bases in the model. Consistent and correct elevations should be used throughout the model.

Patterns of demand use changes during the day were developed in order that time simulations could be run using the EPANET model. These patterns provide a multiplying factor (to be multiplied by the average base flow) in order to get the correct flow value for a particular time interval. Table 4 show the values that were developed for the Pohnpei system. The residential pattern is similar to that which was used for previous studies in Saipan. (Heitz and Khosrowpanah, 2008). We are presently performing a study in Saipan where we are actually using digital water meters to refine these water use pattern estimates. As data from this study becomes available it can be easily added to the Pohnpei water system model.

START TIME	END TIME	AVERAGE TIME	RESIDENTIAL PATTERN	SCHOOLS PATTERN	COMMERCIAL PATTERN	GOVERNMENT PATTERN	DOMESTIC RAIN CATCH PATTERN
0	1	0.5	0.330	0	0	0	0
1	2	1.5	0.330	0	0	0	0
2	3	2.5	0.412	0	0	0	0
3	4	3.5	0.412	0	0	0	0
4	5	4.5	1.287	0	0	0	0
5	6	5.5	1.287	0	0	0	0
6	7	6.5	1.452	0	2.000	0	1.6
7	8	7.5	1.452	2.400	2.000	2.182	1.6
8	9	8.5	1.488	2.400	2.000	2.182	1.6
9	10	9.5	1.488	2.400	2.000	2.182	1.6
10	11	10.5	0.957	2.400	2.000	2.182	1.6
11	12	11.5	0.957	2.400	2.000	2.182	1.6
12	13	12.5	0.957	2.400	2.000	2.182	1.6
13	14	13.5	0.957	2.400	2.000	2.182	1.6
14	15	14.5	1.488	2.400	2.000	2.182	1.6
15	16	15.5	1.488	2.400	2.000	2.182	1.6
16	17	16.5	1.237	2.400	2.000	2.182	1.6
17	18	17.5	1.237	0	2.000	2.182	1.6
18	19	18.5	1.237	0	0	0	1.6
19	20	19.5	1.237	0	0	0	1.6
20	21	20.5	0.825	0	0	0	1.6
21	22	21.5	0.825	0	0	0	0
22	23	22.5	0.330	0	0	0	0
23	24	23.5	0.330	0	0	0	0

Table 4. Water use patterns for the Pohnpei water system

Model Calibration

The completed EPANET model was run several times in order to insure that all components were properly sized and described. This “calibration” process uncovered some short comings in the existing data available to the modelers. The problems uncovered are grouped by topic area.

DEMANDS:

Correct junction demands are key to operation of the entire model. From the beginning of the project it was felt that the PUC had adequate billing data so that high demand users and normal residential demands could be predicted using the PUC billing data. The billing data that was provided by the PUC could not be reconciled. In some cases the total of the high user rates in a route were higher than the total amount reported for the

entire route. These discrepancies were acknowledged by PUC, but updated route and high user data were never provided. Attempts were made to use what data were available but until realistic route usage and high user data are input to the model the model cannot be considered as calibrated. Since the usage values provided are metered usage to the customer, no distribution system losses are included. These losses will have to be estimated and input to the model. Losses to the model can be easily input either junction by junction or through a single demand multiplier for all the junctions.

ELEVATIONS:

Another critical parameter for the model is elevation. Correct junction elevations are essential for computing pressures throughout the system. There appears to be some problems when comparing the tank elevations that were provided by the PUC with elevations shown on the topographic maps. The actual tank base elevations should be rechecked by survey techniques to insure that they are correct. The elevations shown on the topographic map should also be rechecked for compatibility with the local datum. This is essential if the model is ever to produce realistic results.

PUMP CHARACTERISTIC CURVES

Pump characteristic curves were available for all of the well pumps but were unavailable for the lift station at the treatment plant and the hospital MO plant. The lift station pumps were characterized using the name plate operating points. While this allows the model to run, the pumping outputs predicted by the model are much more accurate if actual pump curves are used. Every effort should be made to input the correct pump curves for the new pumps installed at the treatment plant and to obtain the pump curves for the pumps at the hospital MO plant.

Phase III. Development of a GIS database of the water system resources

Using the data developed in Phases I and II, GIS maps and databases describing the Pohnpei water system were developed. The GIS database developed consists of the physical location descriptions of the pumps, pipes, tanks, and valves in the system. System component attributes included parameters such as size, pipe length and diameter, materials, and connectivity to other components of the system. Parameters such as date of installation and condition of the component can be added at a later date wherever available. Most of the data for the GIS was obtained through exportation of the EPANET water system model data. This was accomplished by first inputting the EPANET data files into the Haestad Water system modeling software. The Haestad model has a means of directly exporting the water system component data to ARCGIS shape files. Figure 3 shows the ARCGIS program with the basic system components visible. A sample of the kind of data that is included in the database is shown in Table 6. In this case we have added links to the attribute table for the pump shape file. These links are to graphics showing the pump curves and a picture of the pump site. Maintenance items such as when scheduled maintenance is required could easily be added to the data base. Figure 4 shows linked pictures of the pump station and a linked copy of the pump performance curves. The GIS data files developed are available from WERI.

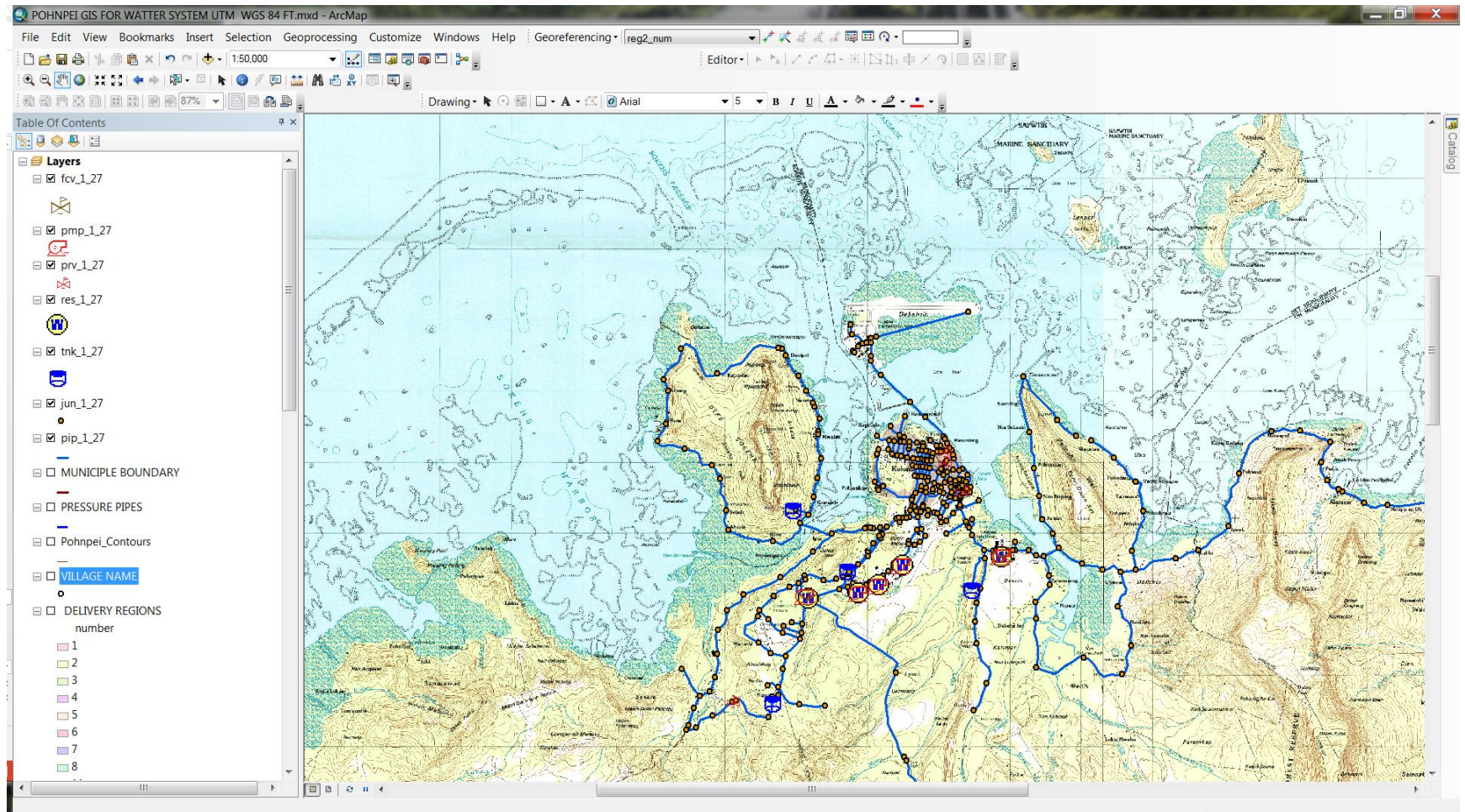


Figure 3. ARCVIEW GIS program showing the basic components of the Pohnpei water system

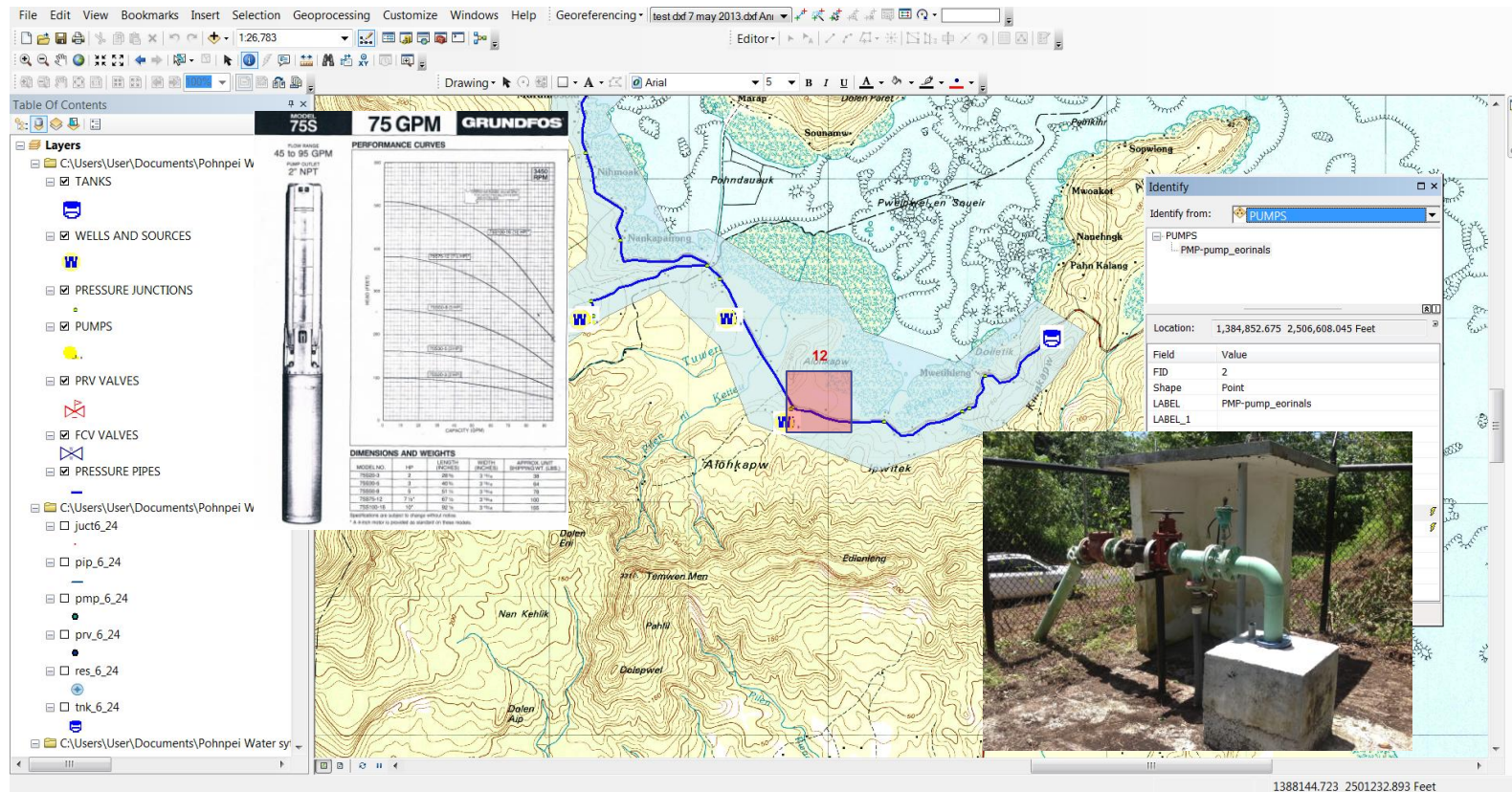


Figure 4. Useful graphical links that have been added to the GIS pump attribute data file

Principal Findings and Significance

A complete water system hydraulic model and GIS database of water system components were developed for the Pohnpei Island water system in Pohnpei State, Federated States of Micronesia. The EPANET program, user manuals and Pohnpei water system input files and the GIS data are available from WERI. The hydraulic model is running but requires further calibration because of lack of accurate and consistent elevations throughout the system. There are large differences in elevations shown on PUC's system maps and the topographic maps used to set the elevations of all components in the system. These differences need to be investigated and a common accurate elevation system applied to all components of the system. These inconsistencies should be remedied to insure accurate model calibration.

A second area of concern is with two of the new wells pumps located in the east end of the system. In the model neither Well "Enrinals" nor Well "Nam Kopotomen" can produce water. The head required is greater than can be produced by the pumps. This could be due to pumping water surface elevations in the wells set to incorrect levels or the elevation at the Kinakapw tank being incorrect. It could also be that the wrong size pump is installed in these wells. These discrepancies should be rectified.

A third area of concern is with the estimates of customer water use and loss rates within the piping system. The metered route usage provided by PUC is not internally consistent at this time. In some cases the sums of the metered high users' rates exceed the total for a particular route. This means that there were errors made in developing the data. PUC needs to recalculate all of the use rates for at least one month and these rates need to be input to the model. It is also essential to model calibration that estimates of losses because of leakage in the system are included in the model. The model can easily account for losses as a percentage of total delivery. At this time loss rates are unknown for the Pohnpei system. As time goes by and leak detection studies are carried out, better loss rate values can be estimated. Hopefully these loss rates will be reduced over time.

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Development of Environmentally Sustainable methods for Treatment of Domestic Wastewater and Handling of Sewage Sludge on Yap Island

Basic Information

Title:	Development of Environmentally Sustainable methods for Treatment of Domestic Wastewater and Handling of Sewage Sludge on Yap Island
Project Number:	2013GU250B
Start Date:	3/1/2013
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	N/A
Research Category:	Engineering
Focus Category:	Waste Water, Treatment, Education
Descriptors:	Wastewater, Treatment, Sludge, Reuse, Septic Tank, Yap, Micronesia
Principal Investigators:	Joe Rouse

Publications

1. Rouse, Joseph D., 2013, "Sustainability of Wastewater Treatment and Excess Sludge Handling Practices in the Federated States of Micronesia," Sustainability, Vol. 5, 4183-4194.
2. Rouse, Joseph D., 2013, Sustainability of Wastewater Treatment Practices in Micronesia, Island Sustainability Conference, University of Guam, Tumon, Guam; April 17-19, 2013.
3. Joseph D. Rouse, 2014, Sustainability of Effective Wastewater Treatment Practices on Yap Island, Regional Island Sustainability Conference; Center for Island Sustainability, UOG. Hyatt Regency, Tumon, Guam; April 15-16, 2014.

PROJECT SYNOPSIS REPORT

Project Title: Development of environmentally sustainable methods for treatment of domestic wastewater and handling of sewage sludge on Yap Island

Problem and Research Objectives

Inadequate treatment of domestic wastewater (sewage) in the Pacific islands has been responsible for serious human and environmental health problems due to contamination of water supplies and damage to natural resources. The reasons for this have often been attributed to the lack of functional technology. On Yap Island in the Federated States of Micronesia, approximately 300 households are connected to the centralized wastewater treatment plant (WWTP), but the treatment being provided is clearly insufficient with nearly raw wastewater being discharged to the ocean. In addition, the numbers and locations of pit latrines and septic tanks on the main island are not adequately inventoried and the degree of treatment being provided is unknown. Furthermore, excess sludge produced at the WWTP is used for agricultural purposes without prior treatment to meet regulatory standards; thus, improved management of this potentially useful resource is an urgent safety concern.

Wastewater treatment requirements vary for different communities throughout the Federated States of Micronesia; however, some similarities in treatment needs on these tropical islands do exist. Accordingly, comparisons of methods being used and results obtained at different locations in the islands will be of value for planning purposes. An accurate inventory of such information, though, is lacking. Information learned from this study would contribute to the documentation of the current conditions of wastewater collection and treatment systems and sludge handling practices. Such information needs to be made available to improve our understanding of where potential problems exist and to assist in planning for future improvements with a goal of developing sustainable wastewater treatment infrastructures throughout the Federated States of Micronesia.

The objective of this project is to contribute to the development of an inventory of up-to-date information on the existing septic tanks and wastewater treatment systems including related sludge handling practices on Yap Island. Furthermore, solutions to existing problems must be developed, including issues pertaining to managerial practices and the need for new and innovative technologies. The findings of this project would assist in identifying and prioritizing areas where further work would be merited to improve the sustainability of wastewater treatment and related practices. Thus, the final technical report will serve as a planning tool to give guidance for potential courses of corrective action on Yap Island and possibly also serve as a guide for other locations in Micronesia.

Methodology

The direct result of this study would be a detailed inventory of up-to-date information of the existing wastewater treatment facilities on the main island of Yap State and documentation of proposed improvements to managerial practices and, where applicable, the need for corrective action or introduction of innovative technologies that would contribute to improved and sustainable outcomes. These items include:

- (i) Identification of locations of individual treatment units (i.e., pit latrines and septic tanks), and evaluation of treatment efficiency (as practicable).
- (ii) Description of the centralized WWTP, including unit processes and flow diagrams and determination of tank volumes and design capacities.
- (iii) Description of excess sludge handling and disposal practices (including quantification as practicable).
- (iv) Identification of sludge treatment methods capable of satisfying regulatory requirements prior to application in beneficial uses as biosolids.
- (v) Discussion of potential improvements/changes to the treatment systems (household or centralized) with respect to health and sustainability.

The methods employed over the course of this project incorporated civil and environmental engineering fieldwork. All work was carried out by the P.I. with some assistance of one University of Guam student. Prior to commencing fieldwork, points of contact in the EPA and utilities offices of Yap State were established to clarify the purpose of our investigation and gather relevant preliminary information.

Fieldwork started by meeting with pertinent local officials on utility boards and other government agencies to review previously received preliminary information and gather additional guidance concerning locations and details of septic tanks and other wastewater treatment facilities. Subsequently, the locations of septic tanks and all other known treatment facilities were confirmed and documented by use of use of global positioning system (GPS) technology, as practicable. Furthermore, the local WWTP and related disposal practices were documented. Photographs were taken for inclusion in the final report.

Upon completion of the fieldwork portion of the project, processing and analysis of field data and preparation of the final technical report commenced. Such work included photo documentation and development of suggestions for improvements that would lead to enhanced sustainability of the treatment systems and improvements to the overall environment and public health. This comprehensive report will be created as a WERI Technical Report and will be distributed to government agencies in the FSM and elsewhere as needed.

Principal Findings and Significance

(i) Septic tanks

Septic tanks are reportedly being used as a first line of treatment for domestic wastewater at 31% of the 2311 households in Yap State (SBOC, FSM), where a household on average consists of six persons. Furthermore it is thought that essentially all of these septic tanks – as concrete box structures – are located on the main island of Yap (a cluster of four nearly adjoining “continental” islands traditionally called “Wa’ab”). Yap Island is inhabited with approximately 7000 persons, or about half of the state’s population.

It was not practicable, nor considered advisable, to attempt to locate and inspect all the household septic tanks, which would amount to an estimated 700 individual units – all

located on private property. The Yap Environmental Protection Agency (YEPA) does not have a full accounting of the numbers and locations of septic tanks because to date there have been no enforceable regulations concerning their construction and placement. The YEPA only makes note of septic tanks when a loan or grant is involved, as with the construction or purchase of a house. Accordingly, over a recent four-year period, only 18 residencies have been formally noted in their Septic Tank System Log. The Loan & Grant Division of the Yap Community Action Program (Yap CAP) does have, though, design drawing for use in new constructions calling for a single compartment septic tank consisting of a 4' X 5' (6' depth) reinforced concrete tank with an outlet to two parallel 20' leaching lines (8' separation). It is doubtful, though, that many residential units employ a leaching field, versus a leaching pit.

At the time of this report, an environmental lawyer was on a two-year assignment with the YEPA to work on development of environmental regulations that would include the construction, placement, and operation of septic tanks and leaching fields, which should start having an impact in the not too distant future. Though not binding in the FSM, the Guam EPA has requirements for placing septic tanks and leaching fields that vary based on the geological features in different parts of the island. Accordingly, for Yap as well, a study would be needed to determine the proper management of septic tanks with respect to the local geological, geographical, and social environments. In addition to the example of a well-developed regulatory system for management of septic tanks on near-by Guam, in the Philippines a National Sewerage and Septage Management Program was recently established to improve sanitation through a combined approach to fecal sludge management and septic tank cleaning (Robbins et. al., 2012). It employs a holistic approach offering advice on such issues as tariffs and fees, cleaning frequency of tanks, and methods to gain participation of the public. Early results show that there is no single right way of implementation, rather adaptation to local circumstances is critical. Nonetheless, lessons are being learned and best management practices are being developed which may also be replicable on Yap and other tropical regions.

The Yap State Public Service Corporation (YSPSC) responds to about three service calls per month to pump out a septic tank, which they provide for a fee of \$90. Only about once per year do they encounter difficulties such as a septic tank being in an inaccessible location or not having an opening (access port) built into the concrete structure. Overall, though, there are no outstanding problems with the use of septic tanks on the island that would demand immediate widespread corrective action. Notwithstanding, the impact of septic tank discharges on the quality of groundwater and possibly even nearby ocean water could be difficult to discern, unless an outbreak of illness were to occur.

With the assistance of the YEPA, it was considered reasonable to conduct a thorough inventory of communal septic tanks as found at Community Health Centers (CHCs, Table 1), Early Childhood Education Centers (ECECs, Table 2), Elementary Schools (ESs, Table 3), and other miscellaneous facilities (Table 4). The precise location of each facility was determined using a high-sensitivity Global Positioning System (GPS, Colorado 300, Garmin) and the general condition and functionality of each unit was

documented. A record of such data could even of interest to the Pacific Disaster Center, which strives to keep an account of important infrastructure in the islands.

As noted in the Tables 1 through 4, many of the septic tanks appeared to be fully functional and a manager was often onsite who was knowledgeable of the system and could attest to periodic servicing. There were some concerns, though, such as the septic tank at Rumuu ECEC (Table 2), which is positioned on the shoreline and encroached by sea water at high tide. In addition, as noted, there were a couple of tanks that were covered over with vegetative growth and one case where the location of the tank could not be visually confirmed (Gilman ES, Table 3), in which cases it is doubtful that proper maintenance is being conducted. Furthermore, at Maap/Tamilaeng ES (Table 3) the septic tank was located down a steep slope in a forest growth and was out of reach of the pump truck. This septic tank was extremely smelly and in due time will no doubt have to be abandoned in favor of a more suitable location.

Table 1. Septic Tanks (STs) at Community Health Centers (CHCs)

	Village/area	North	East	Comments
1	Maap/Rumuung	N9 36.135	E138 10.050	ST appears functional
2	Gagil	N9 32.649	E138 11.080	ST appears functional
3	Tomil	N9 31.583	E138 09.268	ST appears functional
4	Malaav	N9 27.756	E138 03.508	ST appears functional
5	Gilman	N9 27.750	E138 03.507	ST appears functional

Table 2. Septic Tanks (STs) at Early Childhood Education Centers (ECECs)

	Village/area	North	East	Comments
1	Maap	N9 36.146	E138 10.070	ST appears functional
2	Rumuu	N9 32.747	E138 07.571	ST in ocean tidal zone
3	Gagil	N9 32.676	E138 11.191	ST appears functional
4	Tomil	N9 31.588	E138 09.305	ST appears functional
5	Dalipeebinaew	N9 31.323	E138 05.307	ST covered by plant growth
6	Kanifay	N9 28.543	E138 04.111	ST appears functional
7	Gilman	N9 27.759	E138 03.511	ST appears functional

Table 3. Septic Tanks (STs) at Elementary Schools (ESs)

	Village/area	North	East	Comments
1	Maap/Tamilaeng	N9 36.098	E138 09.990	Out of reach of pump truck
2	North Fanif	N9 34.754	E138 06.809	ST appears functional
3	SDA	N9 33.316	E138 08.617	Seven functional STs
4	Rumuu	N9 32.951	E138 07.742	ST under outhouse
5	Bael	N9 32.868	E138 06.029	ST appears functional
6	Gagil	N9 32.684	E138 11.142	Holding tank, no drainage
7	Tomil (B)	N9 31.567	E138 09.339	ST appears functional
8	Tomil (A)	N9 31.531	E138 09.334	ST appears functional

9	Dalipeedinaew	N9 31.314	E138 05.401	“Never been serviced”
10	Kanifay	N9 28.587	E138 04.122	ST covered by plant growth
11	Gilman	N9 27.033	E138 03.754	ST location not confirmed

Table 4. Other Miscellaneous Facilities

	Village/area	North	East	Comments
1	Ablul Outhouse	N9 33.366	E138 08.176	One of two for Ablul
2	Maritime Academy	N9 32.887	E138 09.730	STs not located
3	Daabach Septic Tank	N9 32.278	E138 08.296	Large septic tank
4	Landfill (entrance)	N9 30.982	E138 06.069	New, Fukuoka type
5	Sewage Treatment Plant	N9 30.811	E138 07.641	Imhoff tanks
6	Catholic High School	N9 29.527	E138 04.486	Large retrofit septic tank

(ii) Landfill leachate

While a landfill leachate collection and treatment system would more properly be classified as an industrial operation, due to this landfill being predominately a recipient of domestic solid waste, it will be briefly discussed in this report concerned with “domestic” wastewater. Following in suit with the Fukuoka-type landfill installed on Kosrae a few years ago, Yap State has also elected to construct the same type of landfill (commissioned in April 2014) (see Figure 1). The uniqueness of the Fukuoka-type landfill is that ventilation is employed to promote aerated conditions throughout the landfill with the intent of preventing methane production. Considering that gas produced at landfills is generally not rich enough in methane to be put to use as an energy source, it is deemed more suitable to avoid the anaerobic conditions that normally leads to methane production. This would reduce the potential of methane escaping to the atmosphere where its greenhouse effects would be much greater than that of carbon dioxide, as produced under aerobic conditions.

The leachate pond shown in Figure 2 is holding only rainwater at the time of this report (prior to commencement of trash collection). Overflow from this pond passes through a small sand filter (the white box) prior to being discharged in a forested gully. Effluent samples from the new facility in Yap will most likely have to be analyzed for chemical oxidation demand (COD) and pH. (Standards employed in Kosrae call for COD levels to be maintained below 100 mg/L and pH below 10, which have not been exceeded to date.) If difficulty is met in achieving acceptable discharge levels on Yap (or Kosrae), some form of engineered treatment will have to be employed.



Figure 1. Newly constructed Fukuoka-type landfill on Yap prior to first use.



Figure 2. Leachate collection pond at the new landfill. White box on far side of pond is for sand filtration.

(iii) Sewage treatment

In Colonia, the main residential area and business center on Yap Island, the municipal wastewater (or sewage) treatment plant consists of an Imhoff tank system (Figure 3), which was commissioned around 1974. The plant has two lines designed to operate in parallel; however, only one line is used at a time due to the relatively low intermittent flow entering the plant from only about 300 household connections. While Imhoff tanks are relatively easy to operate and have low operational costs due to the absence of mechanical aeration and internal recycle, they provide only a primary level of treatment consisting of a limited removal of suspended solids. To upgrade to a conventional secondary level of treatment, a completely new plant would have to be constructed with a larger footprint, which would be met with high capital and O&M costs.

However, another method worthy of consideration that could harness biological treatment power with lower operational requirements would be to use an attached-growth (or biofilm) process (Rouse et. al., 2004). Using this method, effective biomass would be retained in the unit process by use of a biocarrier support matrix. Potentially, as a relatively simple retrofit, biocarrier material could be attached to a frame and positioned in the existing tank so as to intercept the flow path of the wastewater. Figure 4 shows the interior of one of the Imhoff tanks drained for inspection, where such a frame could be inserted. Evaluation of such an attached-growth process could be the subject of a subsequent research project (now underway, USGS 2014).



Figure 3. Imhoff tank sewage treatment plant in Colonia, Yap.



Figure 4. Imhoff tank emptied for inspection showing compartment where biocarrier matrix could be inserted.

(iv) Sludge handling

Excess sludge is drawn from the bottom of the Imhoff tanks on approximately a monthly basis (Figures 5 and 6). It is intended that following drying, the sludge should be transferred to the solid waste landfill; however, local farmers scoop it up and use it as fertilizer for food crops. Currently, there is no regulatory guidance in Yap State concerning treatment requirements for sewage sludge prior to use. However, though not binding in the FSM, the US EPA offers widely accepted definitions for different classes of biosolids that could serve as a guideline. Exceptional quality (Class A) biosolids, which have no crop harvesting restrictions, consist of treated residuals that contain no detectable levels of pathogens and low levels of heavy metals. Technologies that can meet Class A standards must process the biosolids for a sufficient length of time at a temperature high enough to yield a product in keeping with the required pathogen cut. Composting is one such method, which can offer an environmentally friendly option to recycle the nutrients and organic matter found in municipal wastewater solids. Depending on the level of treatment achieved, the cured compost could be used for food crop production (if Class A), or for environmental reparation of badlands (if Class B), which are in abundance on Yap.

Rigorous bacteriological testing should be used to evaluate the compost product prior to use. However, where this is not readily possible, if standardized procedures are followed with respect to time and temperature of treatment (i.e., 30 days active composting with internal temperatures 55°C or higher for 15 days; Benedict et al., 1988), the quality of the final product can generally be assumed to meet Class A standards with a reasonable degree of certainty (or at least with more certainty than with the current practice of using untreated sewage sludge). Furthermore, if questions concerning safety should persist due to a lack of testing, applications avoiding contact with food crops, in keeping with more lenient Class B standards could readily be employed. Notwithstanding, it would be a step in the right direction.

As the subject of a subsequent study, a pilot test could be conducted to evaluate the feasibility of developing a suitable composting practice at the wastewater treatment plant. A rough estimate of the quantity of dried excess sludge (ca. 50% solids) comes to only 100 cubic feet, which would be a workable volume, not requiring the aid of special equipment. The benefits of composting would potentially include:

- (a) lessening waste input to the new landfill,
- (b) protecting the public from health hazards,
- (c) repairing badlands, and
- (d) generating some revenue.



Figure 5. Sewage sludge from Imhoff tank being discharged to drying bed.



Figure 6. Fresh wet sewage sludge in drying bed at beginning of drying period

References

- Benedict, A.H., Epstein, E., Alpert, J. Composting Municipal Sludge. Pollution Technology Review No. 152. Noyes Data Corp., Park Ridge, NJ, 1988. 177 pp.
- Robbins, D., Strande, L., Doczi, J. Sludge Management in Developing Countries. *Water 21*, International Water Association. December 2012, pp. 22-25.
- Rouse, J.D., Yazaki, D., Cheng, Y., Koyama, T., Furukawa, K. Swim-bed Technology as an Innovative Attached-growth Process for High-rate Wastewater Treatment. *Japan. J. Water Treat. Biol.* 2004, 40 (3), pp. 115-124.

Information Transfer Program Introduction

WERI's research activities focus predominantly on local water resources problems and issues identified largely through discussions with regional stakeholders at our annual advisory council meetings. Disseminating the results of these investigations to appropriate governmental agencies, environmental managers, policy makers and other local decision makers in the water resources business, has the highest priority and is accomplished in various ways. Institutional technical reports remain a strong vehicle for transmitting such information to our target audiences, many of whom are remotely situated and do not have access to the scientific literature, or require a greater degree of detail than is normally permissible in a standard journal publication. WERI faculty have also become increasingly more interactive with audiences overseas in recent years by sharing their research findings at professional meetings, conferences and workshops at the national and international level. Our recently improved website is gaining increased popularity among professional circles, both at home and abroad, and is now accessible to the great majority of our stakeholders throughout the region. Our annual Advisory Council meetings in Guam, the CNMI and the FSM are highly effective information transfer mechanisms, bringing together people who typically have little to no contact with one another during the rest of the year. These meetings serve as a valuable forum of information exchange and discussion on common issues, problems and needs in the water resources arena. We remain strong in our commitment to teaching and training the up-and-coming water resources professionals of tomorrow, in addition to conducting workshops, courses and seminars for those currently employed in this area. WERI faculty also continue to be major and effective participants in water related law and policy making on Guam by serving as committee members and chairs on numerous governmental boards and by giving testimony at legislative oversight hearings.

One-Day Professional Educators Field Course, with Educational Webpage on the Northern Guam Lens Aquifer

Basic Information

Title:	One-Day Professional Educators Field Course, with Educational Webpage on the Northern Guam Lens Aquifer
Project Number:	2013GU243B
Start Date:	3/1/2013
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	N/A
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Hydrology, Education
Descriptors:	Groundwater education, Aquifer field trip, Aquifer models
Principal Investigators:	John Jenson

Publication

1. Danko Taboro'i and John W. Jenson, 2014, Executive Field Trip Guide to the Northern Guam Lens Aquifer, Water & Environmental Research Institute of the Western Pacific, Island Research & Education Initiative, 36 pages.

PROJECT SYNOPSIS REPORT

Project Title: One-Day Executive/Professional Field Course, with Educational Webpage on the Northern Guam Lens Aquifer

Problem and Research Objectives

The planned military buildup and associated economic growth anticipated on Guam over the next decade has raised concerns regarding sustainable management of Guam's groundwater resources. To arrive at appropriate policy, regulations, and management practices and obtain public support it is essential that policy-makers, water resource professionals, and island educators be equipped with an accurate and up-to-date understanding of the essential characteristics of the island's aquifer and the factors that must be considered to frame and implement sustainable management practices. A universal challenge, however, is that policy-makers, community leaders and other professional people have extremely limited time to engage in instructional opportunities.

Specific critical needs for *Education and Professional Training* identified by the *WERI Advisory Council* that are supported by this instructional program include the following:

- (1) Executive training on water resources for legislators and senior officials
- (2) Community water resources awareness and education
- (3) Teacher training courses in water resources related subjects
- (4) General public training in water resources issues especially in getting technical matters into language the general public can understand

Methodology

We developed and delivered an executive field course for water resource professionals and educators consisting of (1) a single day of intensive personal instruction delivered in the field, with (2) a binder of materials and a supporting webpage containing the instructional materials and links to external resources. Dr. Jenson (field instructor) developed the course content and field trip itinerary. Dr. Taborošī (course material editor) designed and developed a 36-page field guide supported by web-based resources. On the days of field trips, Dr. Jenson rode with the participants in a tour bus, delivering instruction at not only the four selected stops, but during the time between stops.

During the field trip, participants were shown the basement rock that underlies and forms the hydrologic boundary of the aquifer, a large quarry in which the aquifer rock is well exposed, a sinkhole in which rapid entry of water can be observed, and the summit of the highest hill above the aquifer from which the entire catchment can be observed. Between stops, Dr. Jenson delivered instruction from the field guide concerning the basic aspects of aquifer geology, hydrology, and management. Participants included the Commander, Naval Forces Marianas; Consuls General from Japan, Palau, and Taiwan; senior members of the governor's staff; legislators, village mayors, and their staffs. The course was well received and has prompted requests from local agencies, engineering professionals, and educators for future offerings. Figures 1, 2, and 3 show some of the sites visited.

Principal Findings and Significance

This course provides island leaders, water professionals, and island educators with

- (1) A first-hand introduction, in the field, to the Northern Guam Lens Aquifer, including the rock units and watersheds that comprise the aquifer, and the infrastructure by which we extract our drinking water and manage storm water disposal and aquifer recharge
- (2) An understanding of how and where the aquifer captures, stores, releases, and discharges potable water
- (3) An understanding of the considerations that govern successful exploration, development, and protection of groundwater resources
- (4) An introduction to the hydrogeologic conditions and economic factors that constrain resource development and determine appropriate criteria for sustainable management

The itinerary for the trip is shown below:

Senior Executive Field Trip of the Northern Guam Lens Aquifer

11-12 April 2013

Objective: Observe, in a single trip, the floor, the core, and the catchment of the Northern Guam Lens Aquifer and observe the surface features and internal plumbing of the rock units that capture, store, and release water to the island's drinking water production wells.

0800-0900: Van meets and pick up participants at Adelup

0930-1000, Stop #1: The Floor of the Aquifer – the Alutom Formation

- Aquifer basement rock, Mount Alutom. Here we will see examples of the impermeable volcanic rock that underlies the entire Northern Guam Lens Aquifer. This stop also provides an impressive view of the aquifer catchment from the south.

1045-1130, Stop #2: The Core of the Aquifer – the Barrigada Limestone

- Aquifer core rock, DPW Quarry, Dededo. Active quarrying of the limestone here provides some of the island's best exposures of the rock that comprises the core of the aquifer, along with examples of the kinds of porosity that constitute the internal plumbing of the aquifer.

1145-1230, Stop #3: Surface Plumbing of the Aquifer – Sinkholes, Shafts & Caves

- Surface water and sinkhole, Mataguac Hill Peace Memorial Park. In addition to its significance as a World War II historical site, the Peace Memorial Park provides close-up views of outstanding examples of the features by which rapid surface runoff enters the aquifer.

1245-1315, Stop #4: The Aquifer Catchment – Surface of the Northern Guam Plateau

- Vista of Entire Aquifer, Summit of Mount Santa Rosa. This final stop provides a spectacular "big picture" view of the entire aquifer surface, including each of its several basins. Also visible from this vantage point is the land use across the aquifer.

1345-1400: Van returns to Adelup



Figure 1. Senior Executive Field Trip Participants



Figure 2. Dr. Jenson Reviewing the Aquifer Basement Rock



Figure 3. Dr. Jenson Reviewing the Core of Aquifer, Barrigada Limestone

Information Transfer

Basic Information

Title:	Information Transfer
Project Number:	2013GU253B
Start Date:	3/1/2013
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	N/A
Research Category:	Not Applicable
Focus Category:	Education, Management and Planning, None
Descriptors:	Information Transfer, Education, Water Resources
Principal Investigators:	Shahram Khosrowpanah, Shahram Khosrowpanah

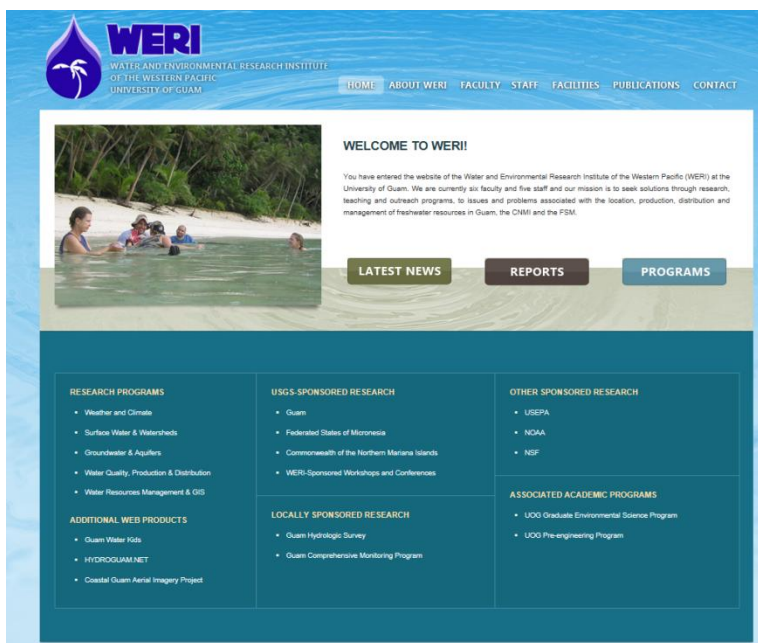
Publication

1. Khosrowpanah, Sh., Danko, Taborosi, 2013, Digital Atlas of Northern Guam, WERI Technical Report No.145, University of Guam, 11pp.

PROJECT SYNOPSIS REPORT

WERI's mission involves a large information transfer-dissemination component. Key elements include written forms such as brochures and pamphlets, a web site, technical reports, journal articles, newspaper columns, and book chapters. The audience for the results of USGS sponsored research is widely varied geographically and by education level. It is important that WERI make this information available in a very widely distributed form.

The WERI web-site is the Institute's primary Information Transfer/Dissemination mechanism. The home page, shown below, is located at <http://www.weriguam.org/>. It features informational links to WERI faculty, staff and Institutional facilities, our current research, education and training activities, primary sponsors and most recent publications. The user friendly format is intended to increase visibility of the Institute's research programs and associated projects particularly for our stakeholders in remote locations where state-of-the-art internet services and computer technology are often lacking.

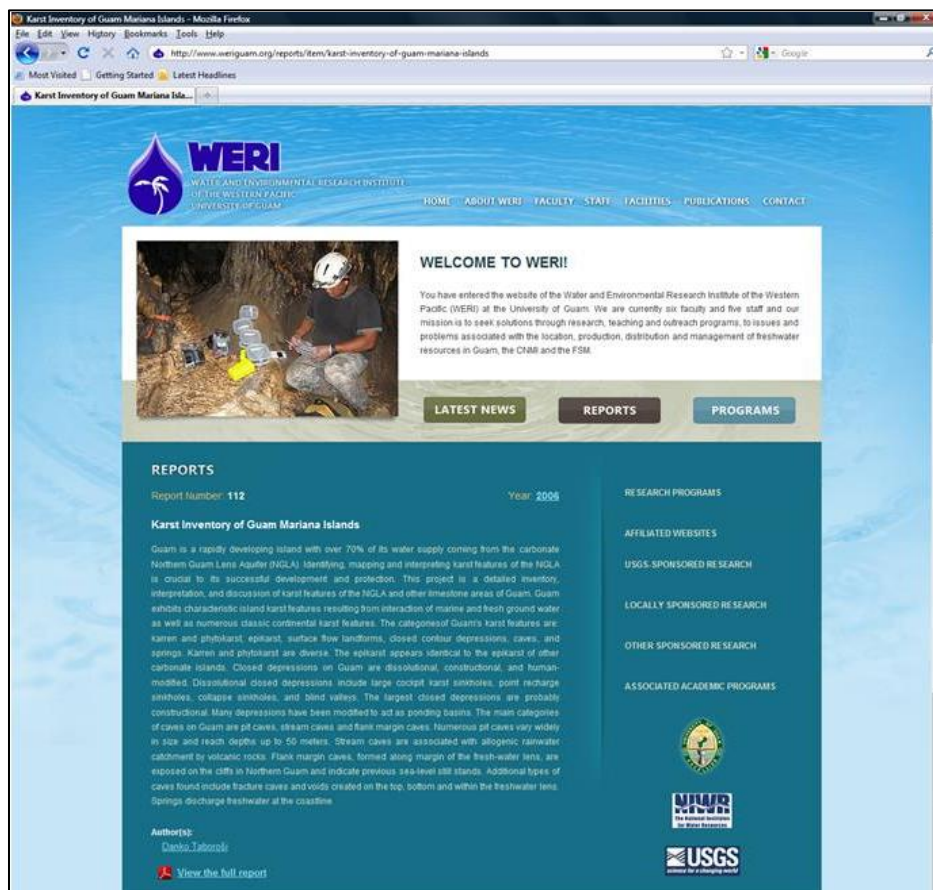


WERI Web-site Home Page

This project also funded the design, layout and printing of five (5) major technical completion reports resulting from USGS funded research projects. Fifty (50) hard copies of each report were printed. All WERI technical completion reports are available in downloadable pdf format on the WERI web-site at <http://www.weriguam.org/reports/list>.

The technical completion report library was updated with several new additions bringing the total number of available volumes to 146. The improved database search engine process for accessing these reports on line utilizes a composite 'Abstract' database for key word searches. Searches based on 'Author' now search all authors in the author string not just the lead author as

before. Upon selection of a particular report, site users are presented with the complete abstract, which may be viewed prior to downloading the main report. An example is shown below.



WERI Reports Page

Because of Guam's remote location, and the escalating costs of air travel, it is difficult and costly for researchers to present their findings at technical conferences and symposiums in other parts of the Globe. A portion of the current Information Transfer Project was earmarked for off-Island travel expenses for PI's and graduate students presenting refereed professional papers summarizing all or a portion of current or past USGS 104-B projects.

In 2005, WERI revealed a unique digital data repository entitled "Natural Resources Atlas of Southern Guam". That resource was inspired by the need for up-to-date baseline information required for sustainable development and other decision making. Its mission was to provide a comprehensive picture of the natural resources found within the fourteen southern Guam watersheds and make that information instantly available to users. The atlas proved to be a highly effective data dissemination hub, as well as a much-used awareness and educational tool. At its core lay a wide range of Geographical Information System (GIS) data for southern Guam, providing valuable support for resource management and research, including hydrologic modeling, pollution prevention, soil conservation, and coastal zone management. The tool became very popular in Guam thanks to its simple and user-friendly data dissemination

approach: all geospatial data are stored and formatted in such a way that the full content is freely accessible on the Internet via www.hydroguam.net address. The web interface also offers a range of additional textual, graphical, statistical, and geographic information to any interested user. Within a relatively short time, the “Natural Resources Atlas of Southern Guam” became so successful that in 2012 it inspired a “sister” project, which was to develop a comparable resource for Northern Guam. That work was completed in late 2013. The new product is entitled “Digital Atlas of Northern Guam” and encompasses many of the strengths of the previously created “Natural Resources Atlas of Southern Guam” with a series of significant improvements. The “Digital Atlas of Northern Guam” is freely accessible on the Internet via: www.hydroguam.net address.

Water Resources of Guam: An Online One-Stop Information Center for Public and Professional Users

Basic Information

Title:	Water Resources of Guam: An Online One-Stop Information Center for Public and Professional Users
Project Number:	2013GU254B
Start Date:	2/18/2013
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	N/A
Research Category:	Ground-water Flow and Transport
Focus Category:	Education, Groundwater, Water Quality
Descriptors:	WEBSITE
Principal Investigators:	John Jenson, Gary Denton, Mark Lander, Joe Rouse

Publications

There are no publications.

PROJECT SYNOPSIS REPORT

Project Title: Water Resources of Guam: An Online One-Stop Information Center for Public and Professional Users

Problem and Research Objectives

The military buildup and ongoing economic growth anticipated on Guam over the next decade has raised concerns regarding sustainable management of Guam's water resources. To support informed public discussion and sound decisions, it is essential that accurate and up-to-date information on the island's water resources along with factors that must be considered to frame and implement sustainable management practices be readily accessible to local and federal policy-makers and agency heads; planners, regulators, and collaborating off-island consultants; and local water resource professionals and educators. Currently, people seeking up-to date information on Guam's water resources and related environmental issues must go to a variety of sources, few of which are equipped to disseminate information or cross-check and verify it with other sources. This project provides a "one-stop" on-line information center to support government, professional, and public activities related to the planning, management, protection, and sustainable use Guam's water resources. It consists of (1) a page on the website of the Water & Environmental Research Institute of the Western Pacific (WERI) hosted by the University of Guam (UOG) Telecommunications and Distance Education Office (TADEO), with (2) links to supporting and related sites containing instructional materials and additional references.

Specific critical needs for *Education and Professional Training* identified by the 2012 *WERI Advisory Council*, which would be supported by this project include:

- General public training in water resources issues, especially in getting technical matters into language the general public can understand
- Training and outreach about protecting watersheds and water resources
- Community water resources awareness and education
- Public education on the costs of water quality
- K-12 education on island water resources and pollution prevention
- Teacher training courses in water resources related subjects

Methodology

This is a pilot project to establish the core materials for a website that can be maintained and modified as appropriate in future years. As it grows and is updated, it will deal with four subjects: (1) rainfall, drought, and recharge for the island's principal aquifer; (2) properties of the aquifer, production, and sustainable development and management of the aquifer; (3) basic information regarding the status of wastewater treatment and advice on acquisition and management of sustainable technologies; (4) current concerns, issues, and advice on groundwater and drinking water quality.

The organization of the One-Stop Info Center is as follows:

- Meteorology: information and graphics on the climate of Guam, most especially rainfall and drought patterns and cycles that affect aquifer recharge

- Hydrogeology: similar materials on the properties of the aquifer, including advice and suggestions regarding sustainable development and management
- Water treatment: tutorial information on water treatment status of Guam and the most appropriate and promising technologies and methods for managing waste water disposal and treatment
- Water Quality: most significant water quality problems on Guam and how best to manage water quality threats on Guam

Principal Findings and Significance

This resource provides working-level water resource officials, professionals, and educators with

- Readily available, centralized, concise and accurate information on the Northern Guam Lens Aquifer, including rainfall and recharge, water storage and flow, pumping, and discharge; waste water production, treatment, and challenges; and water quality conditions and issues
- Citable sources for the development of public documents, including Environmental Impact Assessments, public regulations and statutes, and educational materials

The information provided here also dovetails with other resources developed over the past several years, which are also accessible from WERI's website. Three years ago, WERI put in place a Hydrologic Atlas of Southern Guam (www.hydroguam.net). During the past year, the Hydrologic Atlas of Northern Guam was added. In 2013, WERI added the Northern Guam Lens Aquifer Database, and updated of the Basement Topographic Map of the Northern Guam Lens Aquifer. These are important technical references for specialists who already have an understanding hydrology in general and Guam's resources in particular. The One-Stop information provided by this project, provides a more basic and introductory resource, which will enable first-time users and non-specialists to understand and make use of the more technical resources.

USGS Summer Intern Program

None.

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	0	0	0	0	0
Masters	5	0	0	0	5
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	5	0	0	0	5

Notable Awards and Achievements

During the 2013-2014 academic year, the University of Guam undertook a thoroughgoing assessment of its programs, in preparation for a major re-prioritization and realignment of resources between programs, ranging from elimination of the weakest to heavy reallocation and investment in the strongest programs with the greatest potential. Initiated two years ago by the university president, the final plan was recently approved by the university's Board of Regents. From among the 60 academic and research program units that were evaluated in terms of demand and quality, WERI was one of nine selected as the university's flagship programs, which will receive heavy additional investment and expansion over the next several years. Starting in fall 2014, it will receive at least one additional faculty position, with the prospect of additional staff positions in the next year or two, and acquisition of new and expanded laboratory facilities by 2020. Significantly, among the second tier of twelve programs selected for additional investment is the university's Graduate Environmental Science Program, for which the WERI faculty have been the backbone. The six WERI faculty constitute one third of the program's 18 faculty, but have advised two-thirds (30) of the 45 graduates the program has produced in its 15 years of operation. Ninety percent of the program's graduates are employed in environmental positions in industry, government, and education. About 20% have earned or are enrolled in PhD programs.

Publications from Prior Years

1. 2012GU223B ("Inventory and Assessment of Existing Sewage Treatment Facilities and Excess Sludge Handling Practices in the Federated States of Micronesia") - Water Resources Research Institute Reports - Rouse, Joseph D., 2013, Inventory and Assessment of Existing Sewage Treatment Facilities and Excess Sludge Handling Practices in the Federated States of Micronesia, WERI Technical Report No. 147, Water and Environmental Research Institute of the Western Pacific, Univ. of Guam, Mangilao, Guam, 22 pages.
2. 2007GU95B ("Mercury Contamination in Garapan Lagoon, Saipan: An Evaluation of Potential Drainage Pathways and Impact on Fisheries Resources ") - Articles in Refereed Scientific Journals - Morrison, R. John, Gary R.W. Denton, G.R.W., Ulukalesi Bale Tamata and Julien Grignon, 2013, Anthropogenic Biogeochemical Impacts on Coral Reefs in the Pacific Islands - An Overview. Deep-Sea Research, II. 6: 5-12.
3. 2005GU54B ("Heavy Metals in Biotic and Abiotic Components of a Guam Reef Flat Impacted by Leachate from a Municipal Dump") - Articles in Refereed Scientific Journals - Morrison, R. John, Gary R.W. Denton, G.R.W., Ulukalesi Bale Tamata and Julien Grignon, 2013, Anthropogenic Biogeochemical Impacts on Coral Reefs in the Pacific Islands - An Overview. Deep-Sea Research, II. 6: 5-12.
4. 1991GU02B ("Manganese in Watershed Environments of Southern Guam: Part I, Baseline Study of Sources, Sinks and Speciation") - Other Publications - Denton, Gary R.W, 2013. Metal Deficiencies and Imbalances in Wetland Plants from a Manganese-Enriched Wetland in Southern Guam: A Possible Lytico-Bodig Connection? (Abstract) Annual General Meeting, Asia Pacific Academy of Science and Environmental Management, American Memorial Park Auditorium, Saipan, November 20-21, 2013.
5. 2009GU162B ("Influence of Stormwater and Wastewater Discharges on the Distribution and Abundance of Heavy Metals in Sediments from Saipan Lagoon") - Articles in Refereed Scientific Journals - Denton, Gary R.W., Carmen A. Emborski, Nathan C. Habana, and John A. Starmer, 2014. Impact of Urban Runoff, Inappropriate Waste Disposal Practices and World War II on the Heavy Metal Status of Sediments in the Southern Half of Saipan Lagoon, Saipan, CNMI. Marine Pollution Bulletin Pollution Bulletin, 81: 276-281.
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